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Engineering/Cost Evaluation of Options for Removal/Disposal of NC Fines

(Task Order Number 3/Subtask 3.5)

Final Report

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An evaluation of the various options for recovering and treating/disposing of the nitrocellulose (NC) present in the manufacturing wash streams at the Radford Army Ammunition Plant (RAAP) was undertaken by Arthur D. Little, Inc., for the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA). The technologies evaluated included:

- Sliding bowl centrifugation for preconcentration;
- Cross-flow microfiltration for final concentration;
- Solid bowl centrifugation for final concentration;
- Incineration for disposal of NC sludge; and
- Alkaline digestion for pretreatment prior to biological treatment for disposal.

The evaluation focussed on the economics of the various technologies, but also addressed the performance characteristics and technical risk associated with implementation of

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the various process options which could be configured from the evaluated technologies.

In carrying out the evaluation, a total of ten (10) technology modules were configured and evaluated. The different modules represented variations in the expected performance of these unit operations under extremes in operating conditions. The ten modules were then configured into ten (10) process options. The overall process options were ultimately subjected to an economic assessment and overall evaluation and ranking.

The most desirable options, all involved the use of cross-flow microfiltration as a concentrating/recovery step. Likewise, alkaline digestion as a method for pretreatment prior to biological treatment/disposal was involved with the majority of the most promising options.

Two of the three options with the lowest capital and operating costs also involved both cross-flow microfiltration and alkaline digestion. As a result of this work, it is recommended that a pilot test program be conducted to further investigate cross-flow filtration and alkaline digestion as the preferred methods for concentration/recovery and disposal of NC fines.

TABLE OF CONTENTS

Pages C-8 thru C-11 Should be deleted in this report.
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LIST OF TABLES

LIST OF FIGURES

1.0 SUMMARY

An evaluation of the various options for recovering and treating/ disposing of the nitrocellulose (NC) present in the manufacturing wash streams at the Radford Army Ammunition Plant (RAAP) was undertaken by Arthur D. Little, Inc. for the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA). The technologies evaluated included:

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2.0 INTRODUCTION

The manufacture of nitrocellulose (NC) at Radford Army Ammunition Plant (RAAP) in Radford, Virginia, generates waste streams containing NC fines. RAAP, in conjunction with the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), is evaluating alternative technologies for treating the NC-containing waste streams to achieve a discharge of 25 ppm suspended solids.* To assist in the evaluation, Arthur D. Little, Inc. was contracted by USATHAMA under Contract No. DAAK11-85-D-0008 to evaluate the technical feasibility of the various process options and to do a preliminary comparative economic assessment for screening the alternatives.

A brief overview of the NC process with a description of the waste stream sources and the alternative technologies evaluated are provided in the following subsections.

2.1 The NC Process

A process flowsheet showing where the waste streams are generated is given in Figure 2-1. Quantities of the various waste streams illustrated in the figure are shown in Table 2-1. The quantities are for a single manufacturing line. RAAP has three manufacturing lines; currently one line is fully operational and approximately one quarter of the second line is also in use.

In summary, cotton linters and/or wood pulp cellulose is nitrated using nitric (HNO_3) and sulfuric (H_2SO_4) acids at 30 to 34°C for approximately 25 minutes. This material is centrifuged and washed to remove the bulk of the acid. These highly acidic wash waters containing a small quantity of easily settled fibers, are sent to the boiling tub settling pits. The discharge from these pits is a relatively clear water which is sent to an acid sewer.

The crude product from the nitrators is then subjected to a prolonged (70 hour) boil with fresh water to remove acidity. The product is then cut and beaten (to reduce the average particle size) in a slightly alkaline water (to reduce residual acid content). It is then poached with boiling soda (to stabilize the NC), washed and screened (to remove bulk water) and sent to a blending operation and finally a wringer to be once again washed with water. All wash and transfer waters used or

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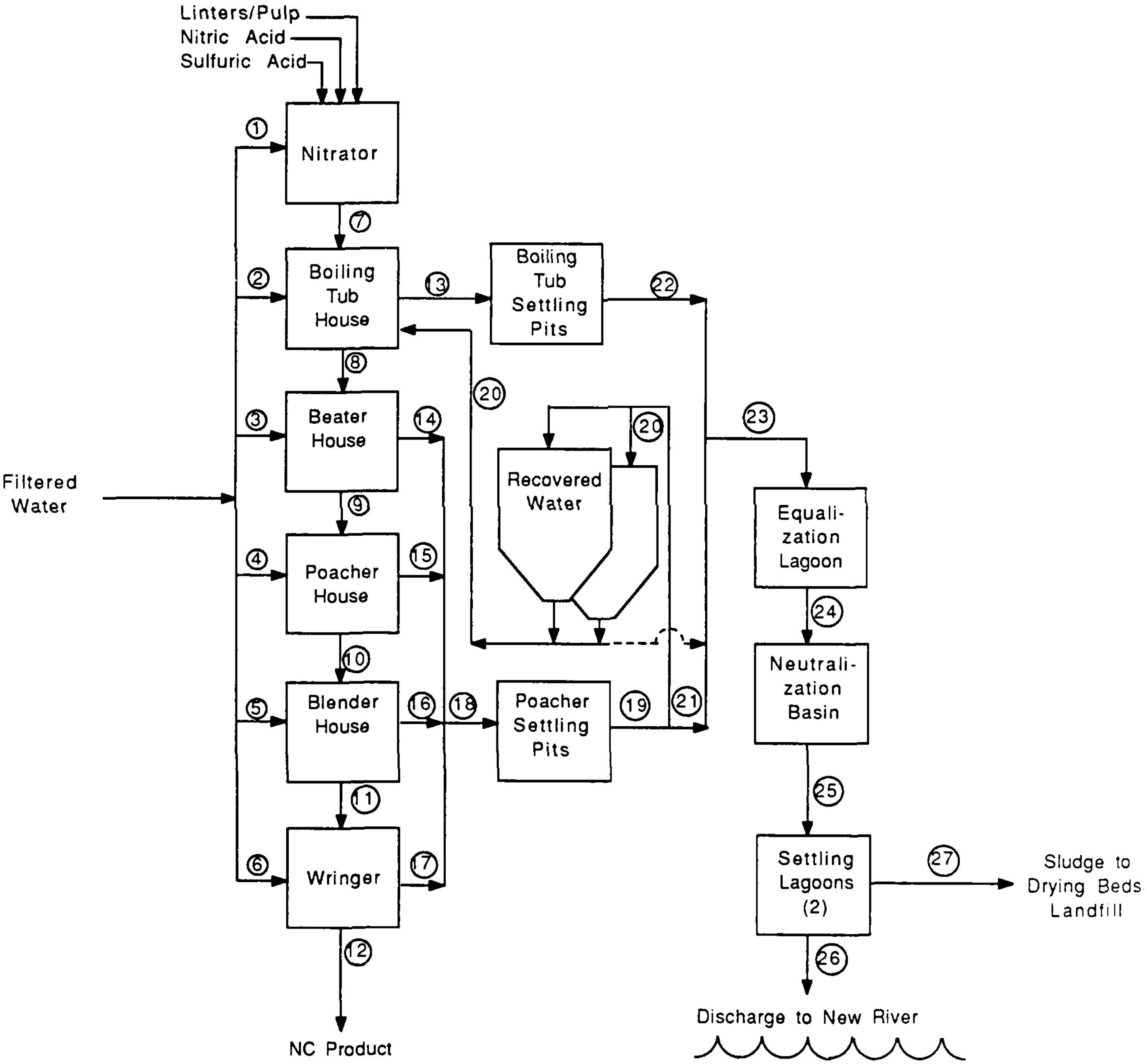
*It should be noted that the suspended solids discharge from the plant results from nitrocellulose fines and calcium sulfate particles formed during neutralization of the acidic waste stream. The present National Pollutant Discharge Elimination System (NPDES) permit limitation for the NC and Acid Areas wastewater at RAAP is 40 ppm. This limitation is presently being complied with by the RAAP pollution abatement systems. The goal of <25 ppm used in this study, reflects the proposed Ammunition Procurement and Supply Agency (APSA) standard for producing an effluent containing 25 ppm suspended solids. This standard has not been imposed on RAAP.

Figure 2-1

Generalized Flow Diagram For NC Manufacturing And Wastewater Generation



Source: Arthur D. Little, Inc. based on information provided by RAAP personnel.

TABLE 2-1

WASTE AND PROCESS WATER FLOWS
FOR ONE NC MANUFACTURING LINE

Stream No.	Water (lbs/day)	Water (10^6 gal/day)	NC (ppm)	NC (lbs/day)	Dissolved Solids (lbs/day)	Note	pH
1		0.050					
2		0.800					
3		0.110					
4		0.455					
5		0.488					
6		0.040					
7		0.050					
8		0.606					
9		0.315					
10		0.360					
11		0.200					
12		----					
13		1.014					
14		0.401					
15		0.410					
16		0.648					
17		0.240					
18		1.699					
19	14.17×10^6	1.699	143	2,000	1,000		7
20		0.200					
21		1.499					
22		1.014					
23		2.513		2,000	20,000	d.s. as H_2SO_4	2
24		~2.5					
25		~2.5					
26	$\sim 20 \times 10^6$	~2.5	25	500			

Source: RAAP

generated in the beating, poaching, blending and wringing operations are discharged to the poacher settling pits. These waters are neutral to slightly alkaline and contain a mix of short fibers and colloidal fines which are generated during the beating operation. The larger fibers (pit cotton) are settled in the poacher pits and are collected for blending back with bulk product. The smaller fibers and colloidal solids are carried forward (as outflow from the settling pits) to either a recovered water storage tank (for reuse in the boiling tub house) or discharged to the acid sewer along with the outflow from the boiling tub settling pits.

The acid sewer discharges to a single, synthetic membrane lined equalization lagoon where some settling of the NC fines occurs. The outflow of the lagoon is sent to a neutralization basin where lime is added to neutralize the water (acidity is primarily H_2SO_4). The neutralized water is then sent to one of two lagoons where additional fines and calcium sulfate ($CaSO_4$) precipitate are allowed to settle. The lagoons discharge directly to the New river.

NC fines removal and subsequent disposal has been practiced at two points in the process. In the past, the excess pit cotton has been removed from the settling pits and set out to dry prior to open-pad burning. The final settling lagoons containing NC fines and $CaSO_4$ sludge are periodically drained and settled sludge is transferred to a drying lagoon. The sludge contains only 1 to 2% NC fines and can be easily handled and is safe to landfill on-site.

RAAP's major problems with the generation and accumulation of NC fines relate to the accumulation of NC fines in the recovered water tanks, the accumulation of fines in the equalization lagoon, and the continuing source of fines in the discharge from the poacher settling pits. Estimates of the quantities of material in each of the two recovered water tanks and the equalization lagoon are shown below:

Item	Volume (gallons)	Current Fines Accumulation (lbs)	pH
Recovered Water Tank #1	1.0×10^6	400,000	7
Recovered Water Tank #2	0.2×10^6	70,000	7
Equalization Lagoon	3.0×10^6	500,000	<2

Approximately 2,000 lbs per day of fines are discharged with the poacher pit overflow of which one quarter or approximately 500 lbs is ultimately discharged to the river. It is believed that the primary solution to the NC fines problem is removal of the fines from the poacher pit overflow. If this is accomplished, NC fines accumulation should cease in the recovered water tanks and the equalization lagoon.

The basis of our evaluation was the treatment of Stream 19 in Figure 2-1 14.2×10^6 lbs/day (1.70×10^6 gal/day), containing 2,000 lbs/day of NC fines for a single manufacturing line.* Any method for treating and dewatering fines from the poacher pit overflow might be applied to the material in the recovered water tanks on a one-time basis. Likewise, the material accumulated in the equalization lagoon might be treated with special consideration of the probable instability of the accumulated fines due to the low pH of the lagoon.

2.2 The Technologies

Several methods of NC fines removal have been tried by RAAP personnel and others. Potential methods have been reviewed recently by John Brown Associates, Inc.[1] and RAAP personnel.[2]

More than ten years ago, RAAP installed 24 sliding bowl centrifuges (seven operating/one spare per line) capable of handling the entire poacher pit overflow from the three manufacturing lines (approx. 5.1×10^6 gal/day). The prototype testing of a sliding bowl centrifuge indicated that centrate from the separators might be of excellent clarity, while the concentrate might contain approximately 1 to 2% (10,000 to 20,000 ppm) of NC fines.[2] Unfortunately, the concentrate was found to be unacceptable for recycle back into the manufacturing process and was still too dilute to justify separate waste processing. Since RAAP was currently in compliance with its suspended solids discharge, it was deemed impractical to continue to operate the centrifuges or attempt to process the concentrate to a higher concentration for disposal in the waste propellant incinerators. (The incinerators at RAAP are currently not capable of handling much additional NC, particularly as a dilute stream). As a result, the problem still persists and NC fines continue to be generated and accumulate in the equalization basin, final settling lagoons and the recovered water tanks.

After a preliminary review, it was determined that the most promising solutions to NC fines removal, (i.e., those which appeared to be technically feasible and were likely to cost less than other possible alternatives) could be divided into three categories: preconcentration processes, concentration processes, and treatment/disposal processes. The technologies which were retained for evaluation are listed below.

- Preconcentration Process
  - Sliding bowl centrifugation
- Concentrating Processes
  - Solid bowl centrifugation
  - Flocculation and conventional pressure assisted filtration
  - Cross-flow microfiltration

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*All options which were explored took into account the need to treat all three of the manufacturing lines.

- Treatment/Disposal Technologies

  - Alkaline digestion followed by biological waste treatment
  - Incineration

In theory, any method of removal/concentration of the NC fines could be combined with an ultimate disposal method. The possible combinations are shown schematically in Figure 2-2. Before performing the preliminary economic evaluations, however, a careful review was conducted of the various data available in previous reports of studies that addressed the potential removal/concentration and disposal methods.

Several overall process schemes were considered, realizing that each individual operation would require optimization with respect to each operation with which it would be combined. From Figure 2-2, eight major process schemes (options) could be configured. These overall options are summarized in Table 2-2. In addition to the major options, several sub-options are possible depending on the expected performance of the concentrating steps. For example, any option which incorporates either cross-flow microfiltration or flocculation and filtration (conventional pressure assisted) could result in the processing of a range of slurry concentrations. Likewise, even options which theoretically produce slurries of equivalent concentrations (e.g., cross-flow microfiltration and solid bowl centrifugation) will have different separation efficiencies (i.e., approximately 100% for cross-flow microfiltration and approximately 85% for solid bowl centrifugation) and thus different amounts of NC to be treated or disposed of in the subsequent operations. As a result, the number of options and sub-options can be very high and impractical to individually evaluate at this time given the high degree of uncertainty in performance with respect to some of the technologies.

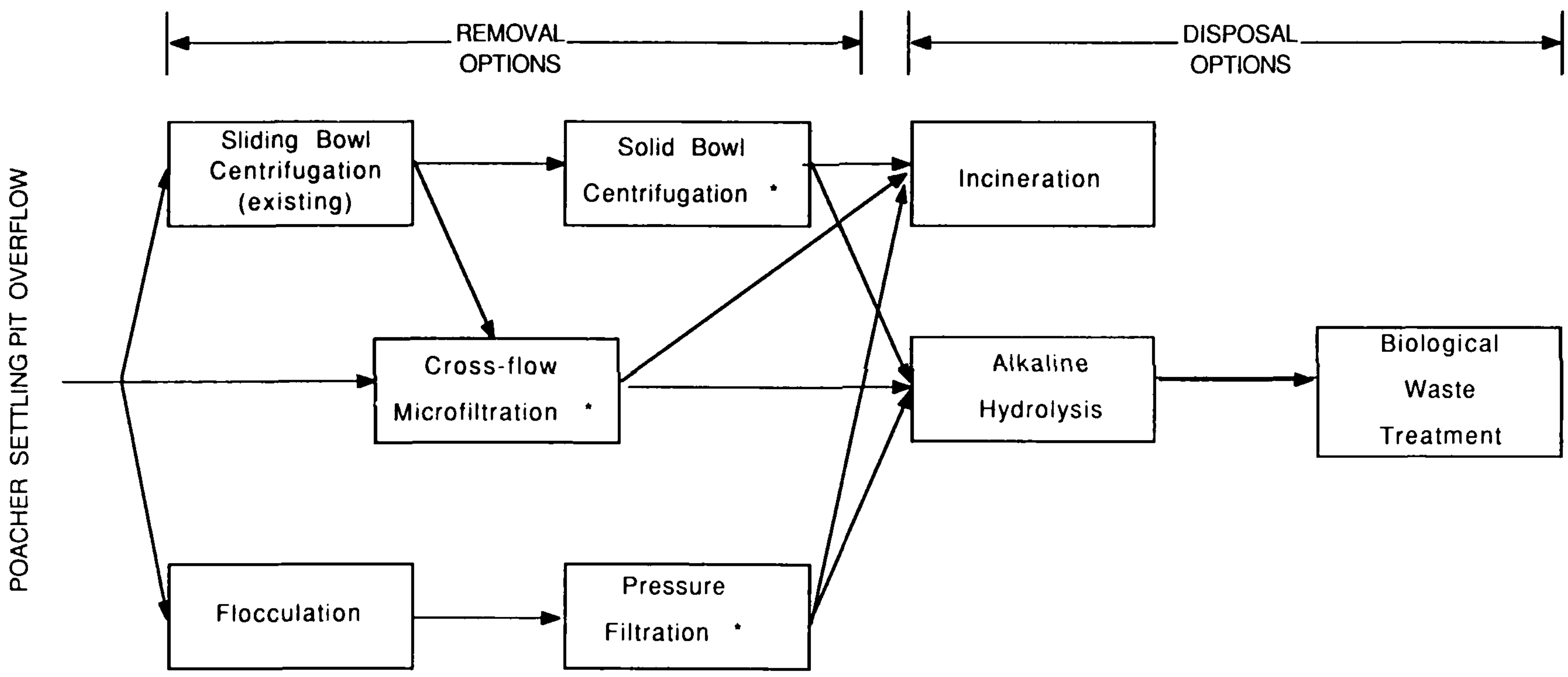
A modular approach was adopted for preliminary assessment which made no attempt to optimize each operation, but rather assumed a reasonable case or cases for each unit operation. Each overall process option was assessed by assembling the appropriate modules (unoptimized) and evaluating the preliminary economics for the combined modules.

A preliminary review of the individual technologies (modules) is contained in Section 3.0. In Section 4.0 the economics are shown for the technologies which were retained* and the overall economics of the process options evaluated.

*Flocculation and pressure assisted filtration was the only technology eliminated from further consideration (see Section 3.2.3).

Figure 2-2

Process Options Initially Considered
for Removal/Disposal of NC Fines



* Filtrate from centrifugation, microfiltration and pressure filtration must have less than 25 ppm solids or additional treatment is required.

Source: Arthur D. Little, Inc.

TABLE 2-2

PROCESS OPTIONS REVIEWED FOR REMOVAL/DISPOSAL OF NC FINES

Option No.	Description
1.	Sliding bowl centrifugation → Solid bowl centrifugation → Digestion/biological waste treatment
2.	Sliding bowl centrifugation → Solid bowl centrifugation → Incineration
3.	Cross-flow microfiltration → Digestion/biological waste treatment
4.	Cross-flow microfiltration → Incineration
5.	Sliding bowl centrifugation → Cross-flow microfiltration → Digestion/biological waste treatment
6.	Sliding bowl centrifugation → Cross-flow microfiltration → Incineration
7.	Flocculation/filtration → Digestion/biological waste treatment
8.	Flocculation/filtration → Incineration

Source: Arthur D. Little, Inc.

3.0 SYSTEMS DESCRIPTION

3.1 Preconcentration Technology

Preconcentrating technologies partially concentrate the poacher settling pit overflow, but for practical or economic reasons cannot concentrate it to a sufficiently high concentration for an ultimate treatment/ disposal technology. Sliding bowl centrifugation was the only technology to fall into this category. Though some of the concentrating processes such as cross-flow microfiltration might be used to partially concentrate the poacher pit overflow, they would probably be used to achieve a high level of concentration of the fines to better interface with the ultimate treatment/disposal technologies.

3.1.1. Sliding Bowl Centrifugation

In 1975, RAAP installed twenty-four DeLaval sliding bowl centrifuges (seven operating/one spare per line) for the purpose of clarifying poacher pit water to less than 25 ppm suspended solids in order to meet the previously proposed Ammunition Procurement and Supply Agency (APSA) standards (see note page 2-1). In addition, it was thought that the clarified centrate water could be recycled for reuse in the NC purification operations and the concentrated NC fines would be recovered by recycling back to the process. It was later determined that the recovered fines could not be recycled. Figure 3-1 is a schematic drawing of the installation. Although the pilot and prototype evaluations showed promising results, the installed centrifuges never met performance expectations and recycle of the concentrated fines was found to be impractical. As a result, the centrifuges were never fully utilized for any length of time.

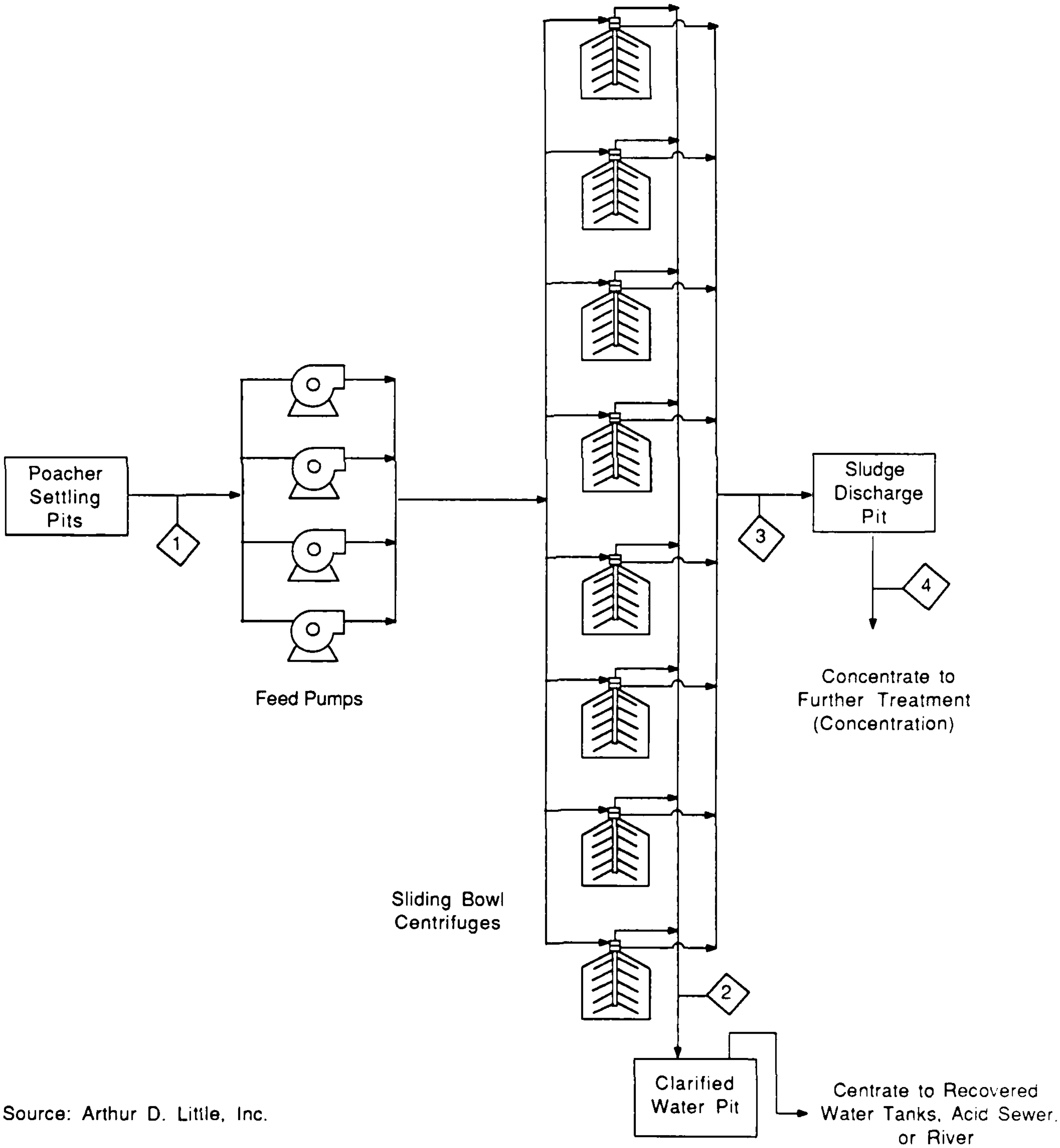
The problems that need to be resolved before the installed system (DeLaval sliding bowl centrifuges) can be relied on as a preconcentration method in future processes for NC fines removal/disposal are:

- Long-term, steady-state operation needs to be demonstrated showing that the full flow rate capacity can be achieved, meeting the clarified centrate goal of 25 ppm suspended solids and still maintain satisfactory particle removal efficiency, i.e., the quality of the concentrate sludge. There is no data on solids removal efficiency and no extended demonstration of attaining the 25 ppm effluent goal with feed fluctuations experienced under typical operating conditions.

- The pilot plant studies showed that the DeLaval centrifuge could concentrate the fines to a slurry of 1 to 3% solids.[3] However, the installed centrifuges achieve a concentration of only 0.03 to 0.10% solids, apparently due to the need for a 30-fold volume of wash water required to discharge the concentrated sludge from the machines. Possible solutions need to be investigated to avoid using such extraordinarily large volumes of wash water.

Figure 3-1

Process Flow Diagram for Sliding Bowl Centrifugation as a Preconcentration Step



Source: Arthur D. Little, Inc.

- Because the original studies focussed on producing a clear centrate, there is very little information on the quality and consistency of the concentrate solids.[3]

- It is unclear as to whether certain problems observed in the evaluation studies have been solved. One such problem has been the accumulation and sticking of solids to the bowl. In an attempt to correct this discharge problem, the centrifuge bowls have been Teflon-coated and special, extra-long disks have been installed to prevent the build-up and bridging of NC particles in the bowl.[3]

- The automatic control system has had difficulty maintaining the quality and consistency of the centrate and concentrate streams with fluctuations in feed condition (temperature and solids concentration). Data was not available on the concentrate, however, during the discharge cycle there was a tendency for solids to be swept out with the centrate raising the NC concentration far in excess of the 25 ppm goal. To solve this wash-out problem, the disk stack was modified and a control scheme implemented to cut-off the feed flow during solids discharge.[3]

If the operation of the sliding bowl centrifuges can be proven to be reliable, it could provide a method of preconcentration of the NC fines. Table 3-1 shows possible material balances which assume relatively high fines recovery by achieving 25 ppm in the centrate (86% recovery in Scenario I and 82% recovery in Scenario II).

Scenario I yields 2.6×10^6 lbs/day of sludge containing 650 ppm suspended solids. It appears to reflect the performance of the current installation. If modifications can be made to the installation to achieve a sludge concentration of 1.5% (Scenario II), as was expected from the pilot and prototype evaluations, the volume of the sludge stream requiring further treatment is only 0.1×10^6 lbs/day, 26 times smaller than Scenario I.

3.2 Concentrating Technologies

3.2.1 Cross-flow Microfiltration

Cross-flow microfiltration is a membrane based technology which has been developed over the past several years and which has found a great deal of acceptance as a reliable separation technique in a large number of successful applications. The technology is an extension of the older membrane-based separation methods of reverse osmosis (RO) and ultrafiltration (UF) It differs from conventional dead-ended filtration in that the process stream to be concentrated is continually swept past the filtering surface (membrane) so that a static layer of solids is not formed and cannot compress on the filter surface to eventually prevent further filtration. The technology is particularly appropriate for colloidal solids (such as NC fines) where precoat filtration is often required. Streams which are currently processed with cross-flow microfiltration include white water wastes from pulp manufacturing

TABLE 3-1

SLIDING BOWL CENTRIFUGATION
MATERIAL BALANCE

Centrifuge Feed	Scenario I		Scenario II	
Poacher Pit Overflow (Stream 1)	Clarified Effluent[1] (Stream 2)	Concentrate Sludge[1] (Stream 3)	Clarified Effluent[2] (Stream 2)	Concentrate Sludge[2] (Stream 3)
Water (lbs/day)				
14.2×10^6	11.6×10^6	2.6×10^6	14.1×10^6	0.1×10^6
(1.70×10^6 gpd)	(1.39×10^6 gpd)	(312,000 gpd)	(1.69×10^6 gpd)	(12,000 gpd)
Nitrocellulose (lbs/day)				
2,000	289	1,711	352	1,648
(143 ppm)	(25 ppm)	(650 ppm)	(25 ppm)	(15,000 ppm)
Dissolved Solids (lbs/day)				
1,000	782	218	993	7

(1) Assumes the centrifuges achieve 25 ppm in the clarified effluent. Also, feed waters are used as concentrate wash waters and the concentrate sludge has 650 ppm solids (0.065% solids).

(2) Assumes the centrifuges achieve 25 ppm in the clarified effluent. Also, feed waters are used as concentrate wash waters and the concentrate sludge has 15,000 ppm solids (1.5% solids).

Source: Arthur D. Little, Inc.

(removes fine cellulose particles for water recycle) and fruit juices (removes colloidal starch particles to produce clarified juices). In these applications, the process streams are concentrated through staged operations to highly viscous toothpaste-like slurries while the microfiltrate is essentially free of suspended solids.

Several years ago, prior to the advent of cross-flow microfiltration, engineers at the U.S. Army labs in Natick, MA, proposed and tested UF as a method of concentrating NC from wastewaters to produce a treatable (or recyclable) sludge and a clarified water suitable for recycle or discharge.[4] Though the technique worked, UF proved to be costly and provided more separation than was required. Also, the processing rates per unit of membrane surface were low, translating into the need for extremely large and costly systems.

As part of our technology evaluation, samples of the RAAP poacher pit overflow have been tested by two suppliers of cross-flow microfiltration technology (Koch/ABCOR, Wilmington, MA, and Millipore Corp., Bedford, MA). The results of these tests are contained in Appendix C. Though the tests were of a limited nature, they were adequate to estimate steady-state flux rates and to provide some indication of the limit to which this stream can be concentrated. Unlike the previous UF tests, flux rates for the microfiltration membranes were quite high, an order of magnitude higher (140 vs. 14 gal/ft^2 day). Consequently, these preliminary results are extremely promising even in the absence of extensive tests and attempts to optimize operations.

The proposed process modules for cross-flow microfiltration are shown in Figures 3-2 and 3-3.

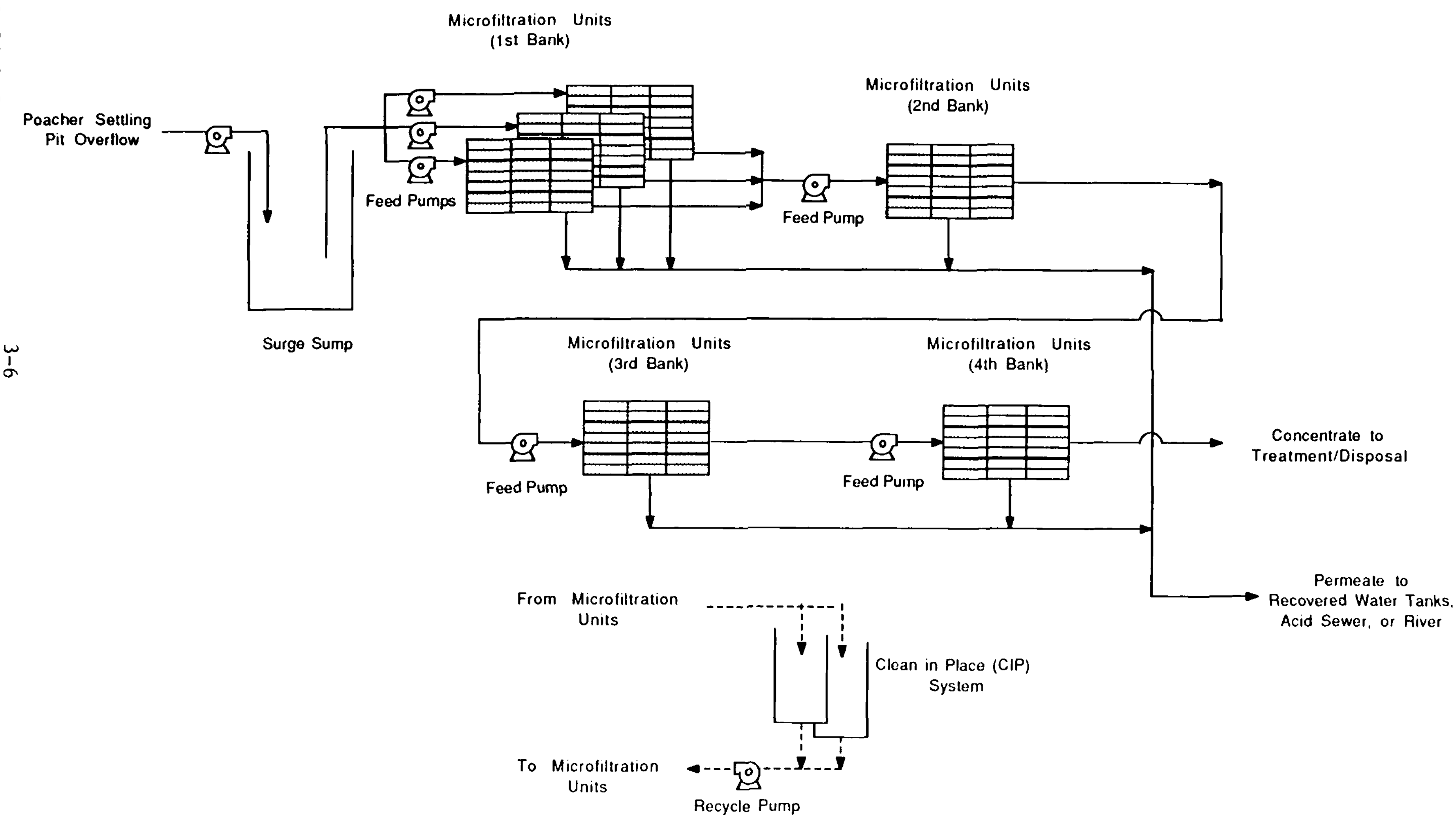
Two basic options were considered. The first involves processing the poacher settling pit overflow directly, that is, without any preconcentration. This scheme is shown schematically in Figure 3-2. In this case, water is pumped from the poacher settling pit to a surge sump (one hour holding capacity). Water is withdrawn from the sump to a bank of microfiltration units which concentrate the overflow waters approximately 10-fold. The concentrate is fed to a second bank of microfiltration units which remove an additional 8.0% of the original water, raising the NC concentration 5-fold or 50 times the original concentration. This material is then fed to a third bank of filters which remove an additional 1.5% of the original water, raising the concentration another 4-fold or 200 times the original concentration.

The final microfiltration unit removes an additional amount of water (approximately 0.4% of the original amount) to raise the final concentration of NC approximately 1,000 times the original. This overall process is continuous in nature and is referred to as stages-in-series.

The second option considered involves concentrating the centrate from the sliding bowl centrifuges (that is, the poacher settling pit overflow after preconcentration). This scheme is shown schematically in Figure 3-3. In this case, the volume of water to be treated is greatly reduced and requires a slightly different mode of operation. The centrate is

Figure 3-2

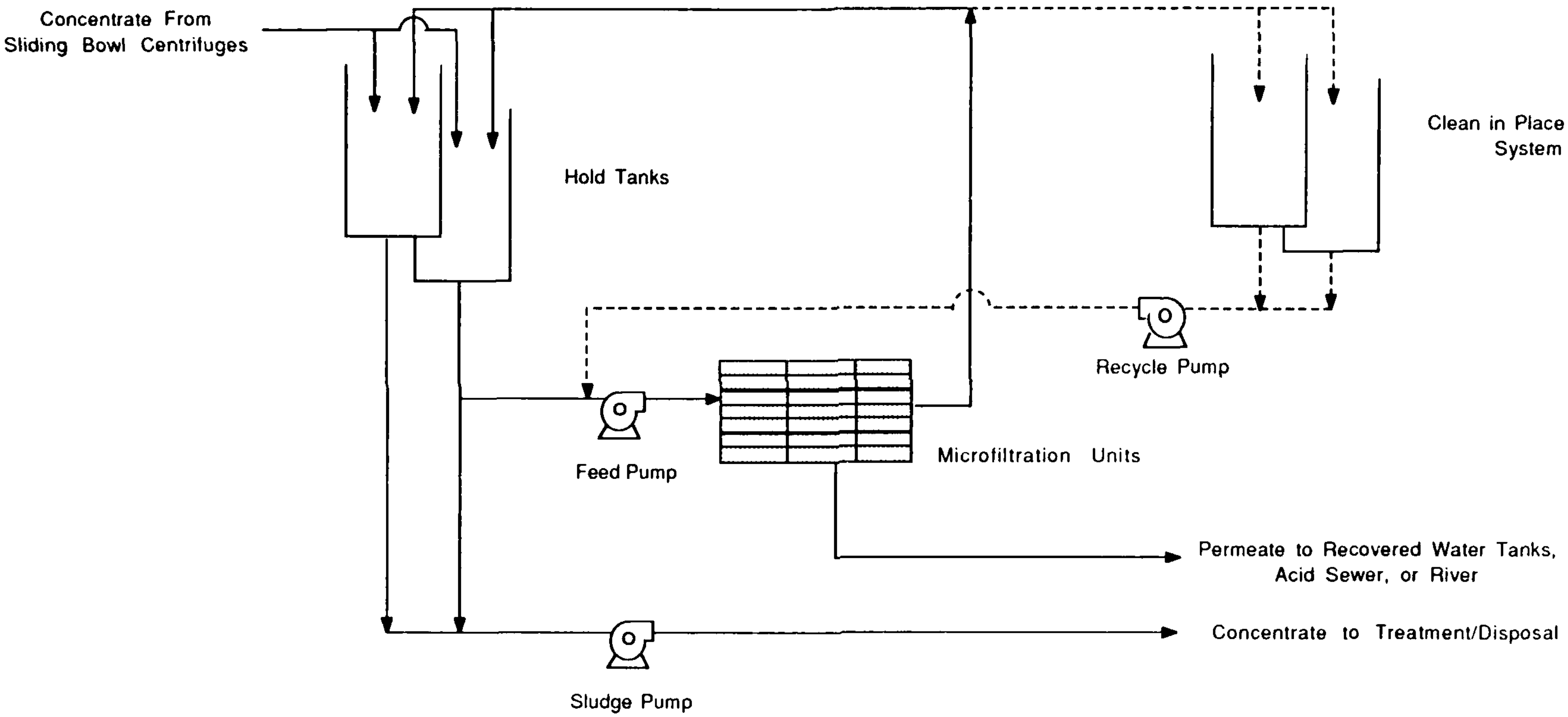
Process Flow Diagram for Cross-flow Microfiltration of a Dilute Feed



Source Arthur D Little, Inc

Figure 3-3

Process Flow Diagram for Cross-flow Microfiltration of a Preconcentrated Feed



Source: Arthur D. Little, Inc.

continuously pumped to one of two holding tanks. The NC is concentrated in the tanks by continuously circulating the contents through a bank of microfiltration units. Once the desired level of NC has been achieved the tank is switched off and the second tank is charged and concentration begins. The concentrate in the first tank is then pumped to final treatment and disposal and prepared for the next cycle. This type of operation is known as fed-batch and is quite commonly used in treating wastewaters.

3.2.2 Solid Bowl Centrifugation

Solid bowl centrifugation might be used to further concentrate a stream that has been preconcentrated by the sliding bowl centrifuges. Figure 3-4 shows the proposed process scheme. The concentrate of the DeLaval centrifuges would be fed to a solid bowl centrifuge, yielding a concentrated sludge material of 20 to 25% solids. Because the volume of water to be treated has been substantially reduced, one machine should be able to concentrate the entire feed stream. The sludge could then go to one of the treatment/disposal methods such as digestion or incineration.

Solid bowl centrifugation has been evaluated by RAAP using a pilot-scale six inch bowl centrifuge manufactured by Bird Manufacturing Company. The evaluation testing of the solid bowl centrifuge, however, did not yield very promising results. The initial testing involved processing the discharge from the DeLaval centrifuges containing 0.03 to 0.10% solids (300 to 1,000 ppm).

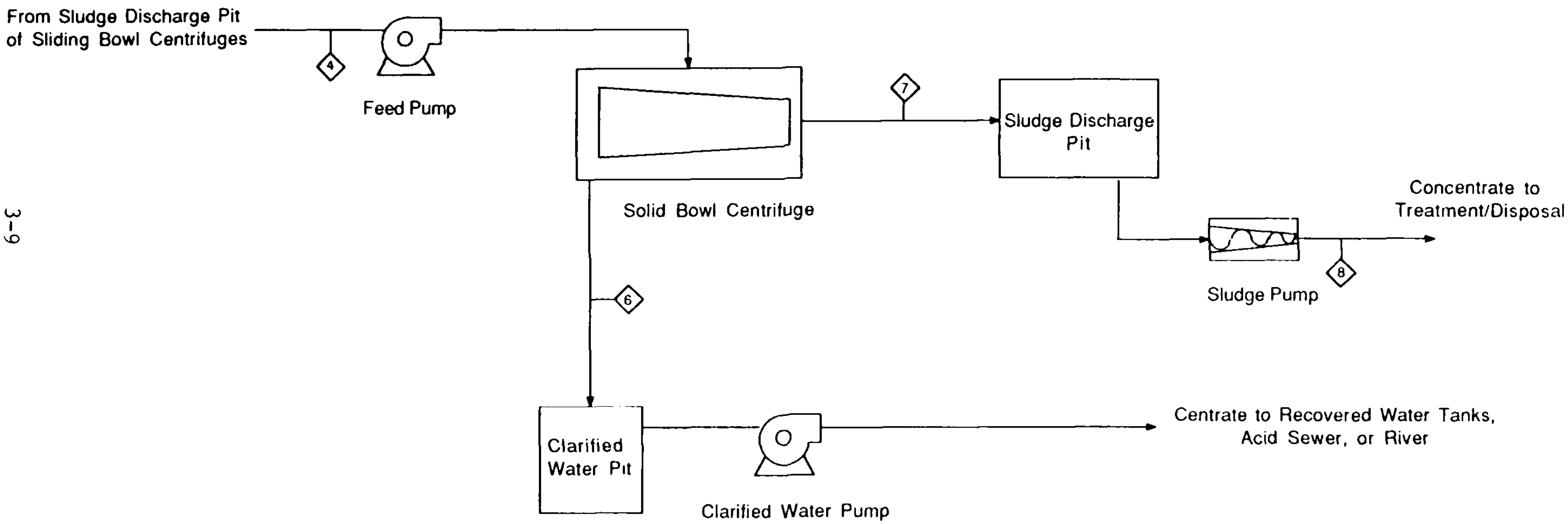
With such a dilute feed stream, it was not possible to operate the centrifuge properly; the build-up of solids on the bowl wall was not sufficient for a discharge of solids as sludge and caused a bearing to overheat.

All further testing was done using a feedstock from the bottom of the sliding bowl discharge pit containing solids of 0.5 to 0.7% (5,000 to 7,000 ppm). This feed stream is approximately an order of magnitude greater than the sliding bowl centrifuges are currently capable of delivering.

Figure 3-5 shows the mass balance required of the sludge discharge pit for the sliding bowl centrifuges to achieve steady-state operation assuming the overflow must meet the 25 ppm discharge limit. <u>To affect the necessary separation and concentration of fines, achieving 25 ppm goal in the overflow and 0.65% solids in the bottoms, the discharge pit must be a better separation device than the sliding bowl centrifuges</u>. The solids recovery would have to be 97% with a ten-fold concentration of feed solids to sludge. Because the overflow from the pit is relatively large, the 25 ppm discharge limit is a likely constraint. It would be difficult to blend off the overflow with the centrate from the sliding bowls unless the centrate were much clearer than 25 ppm. <u>It is unlikely that a pit or other simple clarification device could perform satisfactorily given that the fines have already been settled once in the poacher pits and have also been centrifuged</u>.

Figure 3-4

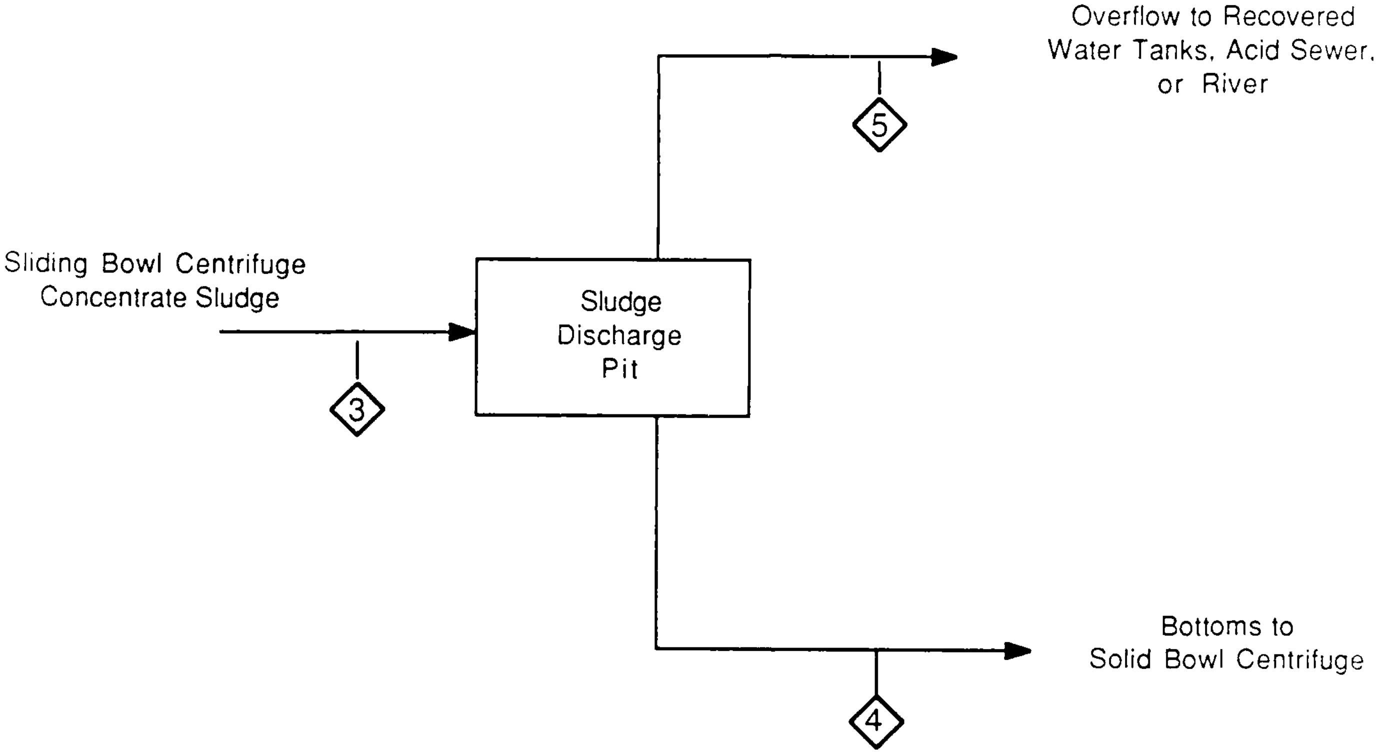
Process Flow Diagram for Solid Bowl Centrifugation
of a Preconcentrated Feed



Source: Arthur D. Little, Inc.

Figure 3-5

Sliding Bowl Centrifuge Discharge Pit
Material Balance



	3	4	5
Water (lbs/day)	2.6×10^{6}	0.25×10^{6}	2.35×10^{6}
Nitrocellulose (lbs/day)	1711 (650 ppm)	1,652 (6,500 ppm)	59 (25 ppm)
Dissolved Solids (lbs/day)	183	18	165

Source: Arthur D. Little, Inc.

Even when processing a feed stream of an appropriate fines concentration, the evaluation study showed mixed results. At a test feed rate of 2 gpm, the solid bowl centrifuge produced a centrate of about 0.1% solids (1,000 ppm) with a feed of about 0.65% solids (6,500 ppm). Solids recovery was about 85%. Table 3-2 is a mass balance reflecting the performance test data. Because the solid bowl centrifuge produces a centrate with a solids content forty times higher than the discharge limit, it would require further treatment or blending off with a very large stream containing much less than the 25 ppm discharge goal, e.g., the 31,000 gallons per day stream containing 1,000 ppm would have to be blended off with a 1.2×10^6 gallon per day suspended solids free stream to achieve the goal of 25 ppm.

Furthermore, the solids content of centrate increased dramatically when the solids content of the feedstock increased. Centrate solids also increased with an increase in feed rate. The solid bowl centrifuge appeared to have a very limited range of feedstock conditions on which it could operate satisfactorily.

Like the sliding bowl centrifuges, an automatic control scheme would need to be developed to maintain the quality and consistency of both the centrate and concentrate streams given the expected fluctuations in feed condition.

Though the solid bowl seemed capable of producing a very high quality sludge, up near 25% solids, long-term operation would have to be confirmed demonstrating there were not problems of solids accumulation and sticking.

In summary, the test evaluations did not provide encouraging data that solid bowl centrifugation could be successfully integrated in a steady-state process. The necessary quality (solids content) of the feed stream to the solid bowl centrifuge could be extremely difficult to achieve. In addition, the poor quality of the centrate from the solid bowl machine would appear to be unacceptable for discharge to the river.

3.2.3 Conventional Pressure Filtration

Conventional pressure filtration was also considered as a separation technique to remove water, thereby concentrating the NC fines. Over the years various kinds of filters (sand, granular, resonating, and vacuum rotary drum) have been considered and tested with poor results.[3] Filter aids such as precoats and flocculating agents have also been evaluated but have not yielded results that would make filtration a viable option. The problem with using conventional filtration equipment to retain the NC particles are their extremely small size, approximately 90% go through a ten micron opening. Usual retention media that might retain the suspended particles such as filter cloths and sand, blind quickly. Very large volumes of precoat material seem to be necessary to produce a clear filtrate making precoat filtration expensive and greatly complicating downstream treatment and disposal methods.

Our contacts with filtration vendors did not result in any breakthroughs to overcome the above problems. We contacted the following vendors: BC

TABLE 3-2

SOLID BOWL CENTRIFUGATION
MATERIAL BALANCE

	Centrifuge Feed from Sludge Discharge Pit (Stream 4)	Centrate (Stream 6)	Concentrate Sludge (Stream 7)
Water (lbs/day)	2.6×10^5	2.6×10^5	4,000
Nitrocellulose (lbs/day)	1,711 (6,500 ppm)	256 (1,000 ppm)	1,455 (26%)
Dissolved Solids (lbs/day)	18	18	0.3

Source: Arthur D. Little, Inc.

Hoesch Industries, Bird Machine Co., Dorr-Oliver, Eimco, and Larox, Inc. Again these contacts did not reveal any new information to indicate that the technical limitations of conventional filtration systems could be overcome to successfully concentrate the very small NC particles in poacher pit overflow water. We, therefore, eliminated conventional pressure filtration from further consideration and pursued microfiltration, a newly developed technology for filtering small particles.

3.3 Treatment/Disposal Technologies

3.3.1 Alkaline Digestion

The alkaline digestion of NC is a method for rendering the material biodegradable. Specific digestion conditions are not yet well defined, but it appears reasonable to assume that a rather harsh treatment with five percent caustic at 90°C for 3 hours should render the finely divided NC suitable for rapid biodegradation.

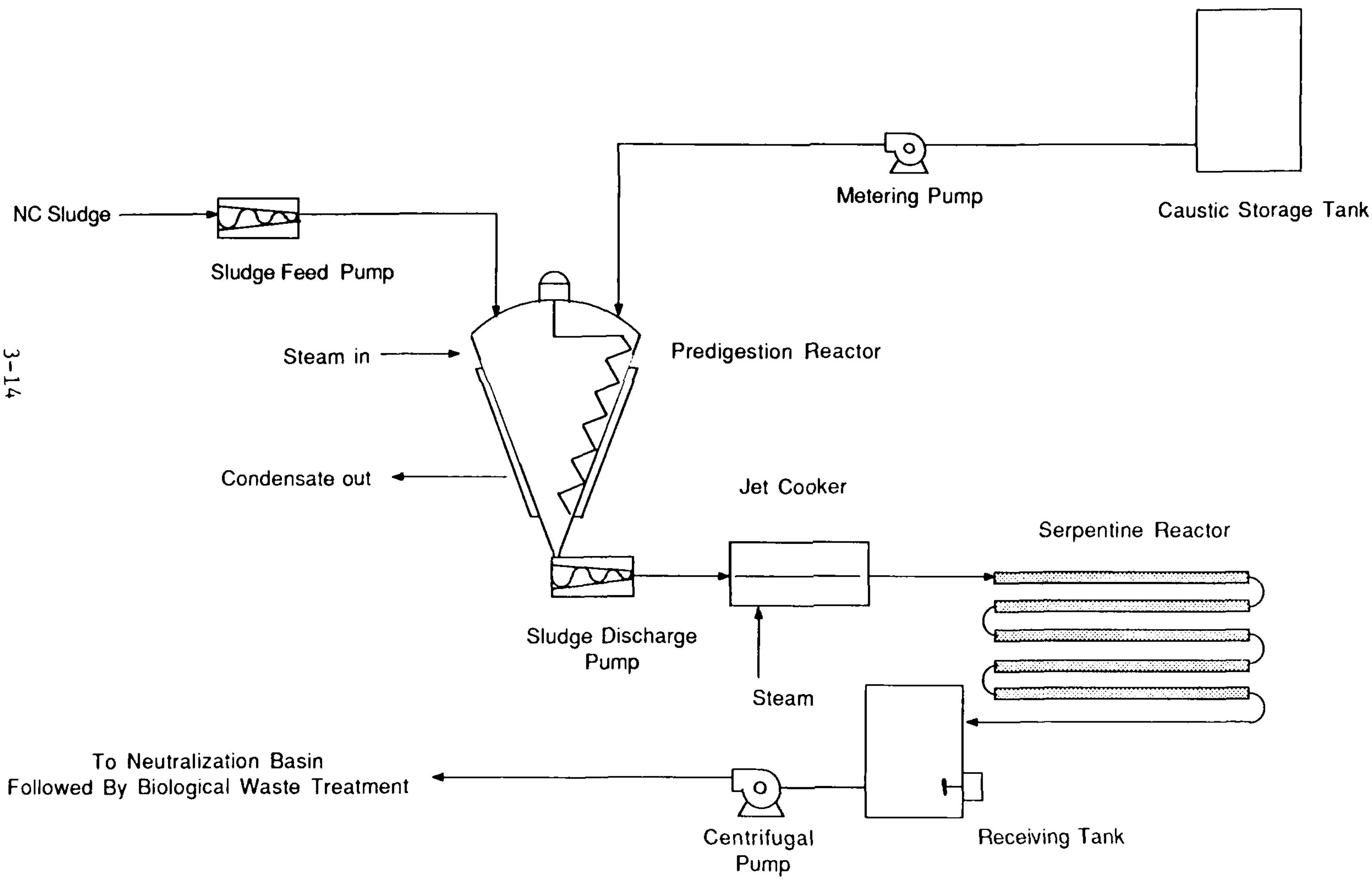
The proposed process module for digestion is shown in Figure 3-6, and is designed as a two-stage operation. Sludge (either 10% or 25% solids) from the concentrating step (cross-flow microfiltration or solid bowl centrifugation) is continuously pumped to a conical predigestion reactor. Forty percent (40%) caustic (NaOH) is metered into the reactor (to sustain a 5% caustic concentration) and the mixture is raised in temperature to 65°C through the use of low pressure steam to the reactor jacket. The tank is designed with a vertical rotating screw which provides the necessary agitation for the thick viscous slurry. The vessel is designed with a continuous bottom discharge and sized to allow for an average one-hour residence time. The slurry is pumped from the reactor bottom to a steam jet cooker where the temperature of the mixture is quickly raised to 95°C through direct steam injection. Exiting the cooker, the material is pumped through a serpentine insulated tubular reactor with a residence time of three hours. The material is discharged into a receiving vessel (surge tank) and then pumped to a neutralization station to be mixed with some of the acidic water from the boiling tub pits (2.5 to 6.0% of the acid water are required to neutralize the caustic hydrolyzate).

The pH-neutral digested sludge is then discharged directly to a biological waste treatment facility. The load to the biotreatment plant would be approximately 1,700 lbs of BOD per day or roughly equivalent to the design capacity of the rotating biological contractors (RBCs) of the existing biotreatment plant at RAAP.

The optimal conditions for hydrolysis and subsequent biodegradation are unknown and as such the expected process performance is somewhat speculative. Wendt and Kaplan have reported on alkaline digestion of 5% gun cotton slurries using 3% caustic (NaOH).[5] At 95°C, the gun cotton was totally solubilized in 30 minutes. It therefore appears reasonable that three hours at an average temperature of approximately 90°C and caustic concentration of 5% preceded by the one hour predigestion conditions at 65°C, should accomplish a complete digestion of the very finely divided NC. In fact, one could speculate that much less severe

Figure 3-6

Process Flow Diagram for
Alkaline Digestion



Source: Arthur D. Little, Inc.

(lower temperatures and caustic concentrations) could accomplish the solubilization.

Wendt and Kaplan have also reported on the biological degradation of digested NC and found that the material could be effectively treated using a three stage, denitrification - activated sludge - denitrification process.[5] It is our understanding that the current RAAP biological treatment plant is nitrate limited and that an NC digest might be beneficial to the performance of the plant. This would mean that the denitrification steps could be avoided and that the digest could be assumed to be just additional BOD load. To accommodate this additional BOD/COD load, the biological treatment plant at the RAAP would have to be expanded. For the purpose of this analysis the cost of expanding the biological waste treatment facility has not been included.

3.3.2 Incineration

It has long been known that incineration of NC sludges is a technically feasible option for final disposal. The current waste propellant incinerator at RAAP is fully committed to processing waste material from the general manufacturing operations. Consequently, there is no excess capacity for handling the approximately 2,000 lbs per day of NC fines in a 10 to 25% water slurry. A new incineration facility would therefore be required to process the concentrates from the filtration or centrifugation options.

Under a separate contract, Roy F. Weston, Inc. (RFW), was asked to review the incineration option and to prepare an economic evaluation of this disposal method.[6] Relevant portions of the final report of this study are attached to this report as Appendix A. Several options were reviewed by RFW which took into account the possible variations in NC content and amount that might be provided by the concentrating options: Case A - 6,000 lbs NC/day at 10%; Case B - 6,000 lbs NC/day at 15%; Case C - 6,000 lbs NC/day at 20%; Case D - 6,000 lbs NC/day at 25%; Case E - 15,999 lbs NC/day at 25%; and Case F - 21,192 lbs NC/day at 20%. The Appendix includes a description of the proposed incineration process and the costs developed for each case. These capital and operating costs were used as input to our analyses.

3.4 Overall Process Systems

Following the technology evaluation, ten process modules were defined and capital and operating costs were determined for each. The process modules which were retained are shown in Table 3-3. Using the ten modules, ten process options were subsequently defined. They are shown in Table 3-4 and summarized schematically in Figure 3-7. Overall capital and operating costs for each process option were developed and compared.

The comparisons were based on criteria that included expected performance (to meet concentration requirements, discharge standards and to recover NC fines), technical risk (level of additional developmental effort required), flexibility (ability to handle varying requirements and fluctuations in wastewater characteristics), capital cost, and

TABLE 3-3

MODULES RETAINED FOLLOWING EVALUATION

Module No.	Code	Description
1	SBC	Sliding bowl centrifugation of poacher settling pit overflow and preconcentrating to 650 ppm
2A	XFMF-DF-10	Cross-flow microfiltration using a dilute feed (poacher settling pit overflow) and concentrating to 10% NC
2B	XFMF-PCF-10	Cross-flow microfiltration using a preconcentrated feed (from Module 1) and concentrating to 10% NC
3A	XFMF-DF-25	Cross-flow microfiltration using a dilute feed (poacher settling pit overflow) and concentrating to 25% NC
3B	XFMF-PCF-25	Cross-flow microfiltration using a preconcentrated feed (from Module 1) and concentrating to 25% NC
4	SOBC	Solid bowl centrifugation using a preconcentrated feed (from Module 1) and concentrating to 25% NC
5A	ADST-10	Alkaline digestion of a 10% NC slurry followed by discharge to biological waste treatment
5B	ADST-25	Alkaline digestion of a 25% NC slurry followed by discharge to biological waste treatment
6A	INCIN-10	Incineration of a 10% NC slurry
6B	INCIN-25	Incineration of a 25% NC slurry

Source: Arthur D. Little, Inc.

TABLE 3-4

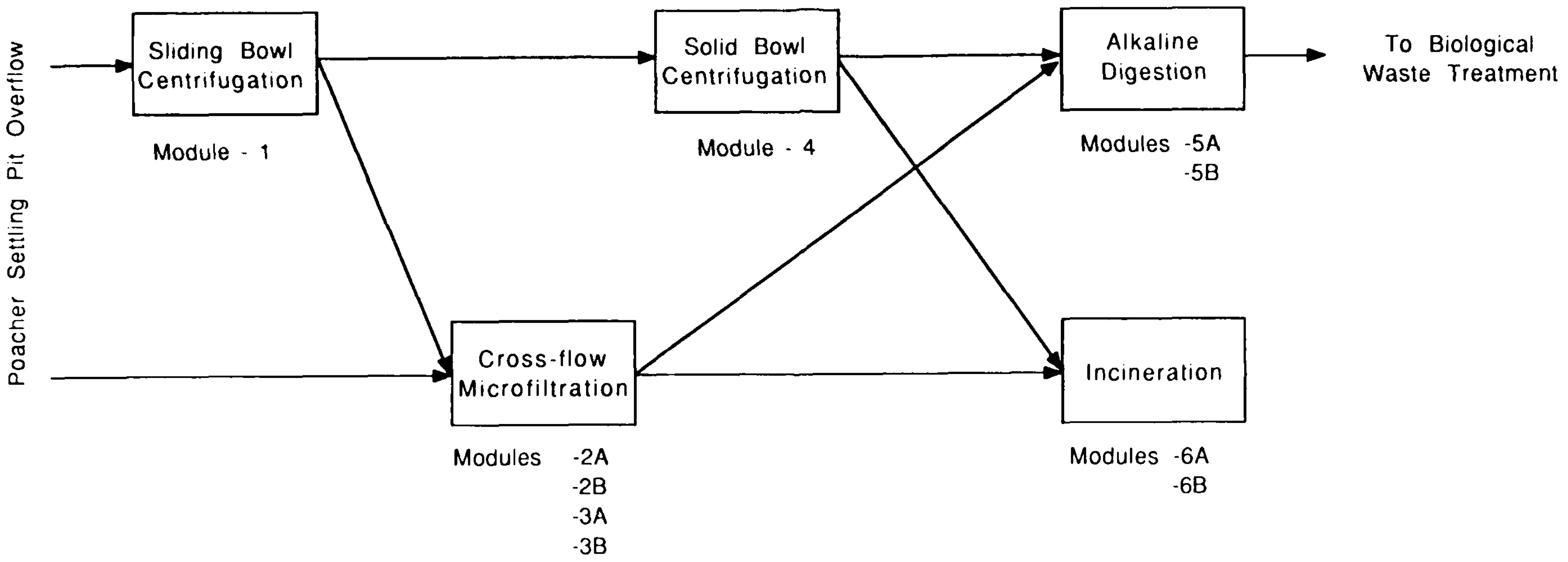
PROCESS OPTIONS (MODULE COMBINATIONS)
EVALUATED FOR REMOVAL OF NC FINES
(Module Numbers refer to Table 3-3)

Option No.	Module Sequence		
I	1 (SBC)	4 (SOBC)	5B (ADST-25)
II	1 (SBC)	4 (SOBC)	6B (INCIN-25)
III	1 (SBC)	2B (XFMF-PCF-10)	5A (ADST-10)
IV	1 (SBC)	2B (XFMF-PCF-10)	6A (INCIN-10)
V	1 (SBC)	3B (XFMF-PCF-25)	5B (ADST-25)
VI	1 (SBC)	3B (XFMF-PCF-25)	6B (INCIN-25)
VII	2A (XFMF-DF-10)	5A (ADST-10)	--
VIII	2A (XFMF-DF-10)	6A (INCIN-10)	--
IX	3A (XFMF-DF-25)	5B (ADST-25)	--
X	3A (XFMF-DF-25)	6B (INCIN-25)	--

Source: Arthur D. Little, Inc.

Figure 3-7

Final Process Options Evaluated for Removal/Disposal of NC Fines



Source: Arthur D. Little, Inc.

operating cost.* The relative importance (that is, weighting) of these criteria was not considered at this time. An appropriate ranking scheme can be developed if the need arises in the future.

*Operating costs were estimated using two methods. The first incorporated the fixed costs of depreciation, taxes, and insurance. The second method ignored these costs since they are not relevant to the economics of a government operation.

4.0 COST ESTIMATIONS AND ECONOMIC EVALUATIONS

4.1 Approach to Cost Estimation

The preliminary process engineering analysis and equipment sizing performed on the NC fines concentration and treatment systems established the basis for estimating the capital investment and operating costs.

For component or subsystem costs, a combination of general published cost curves,[7] current cost estimation manuals,[8] and budgetary quotations from equipment suppliers were used. The Guthrie's Modular Factor method[9] was used to convert purchased component costs to installed costs. The modular factor, specific to each type of equipment, is intended to account for all direct and indirect cost elements in placing a piece of equipment into operation. These cost elements include: engineering, procurement, freight, insurance, taxes, field installation (materials and labor), contractor's fee and contingency. Specific modular factors used along with equipment list and purchased component costs are shown in the equipment lists. All cost data were brought to current first quarter, 1987, by using the Chemical Engineering Plant Cost Index.

Operating costs were calculated from the operating requirements established in the mass balances and equipment sizing calculations as discussed in the previous section. Costs for operating materials were obtained from suppliers. Costs of utilities and other site-specific costs supplied by RAAP are shown in Table 4-1.

4.2 Capital Investment and Operating Cost/Economic Evaluation

For each technology module, a complete equipment list was developed showing major process equipment specifications and costs. These equipment lists are found in Appendix B. To arrive at the total capital investment associated with each technology module, a typical engineering fee (3% of installed equipment cost) and contingency (20% of installed equipment cost) were added to the estimated total installed equipment cost of the module.

The estimated operating costs for each of the technology modules are shown in Tables 4-2 through 4-11. The operating costs are grouped into two categories, variable costs and fixed costs. Variable costs include utilities and chemicals consumed in the process. Fixed costs include items such as labor, plant overhead, maintenance, depreciation, and taxes and insurance. As mentioned previously, fixed costs were estimated using two methods. The first used for a commercial enterprise included depreciation, taxes, and insurance. The second method ignored these costs since they are not relevant to the economics of a government operation.

TABLE 4-1

RAAP UNIT COST DATA FOR ECONOMIC ANALYSIS

Item	Unit Cost
Electricity	$0.036/kWh
Water	$0.23/1,000 gal
Steam	$3.53/1,000 lbs
Labor	
• Op. Supervisors	$24.92/hr
• Op. Labor	$18.67/hr
• Maint. Labor	$26.04/hr

Source: Arthur D. Little, Inc. based on data provided by RAAP personnel.

TABLE 4-2
SLIDING BOWL CENTRIFUGATION
(Module 1)

FEED STREAM:	Poacher Pit Overflow	FEED NC CONCENTRATION:	143 ppm
FEED RATE (3 lines):	5,100,000 gallons per day	CENTRATE NC CONCENTRATION:	25 ppm
CAPITAL INVESTMENT (CI):	$375,000 (upgrading)	CONCENTRATE NC CONCENTRATION:	650 ppm
OPERATIONAL BASIS:	365 days per year	FINES RECOVERY:	86%
ORIGINAL CI (1987 $):	$4,700,000		

OPERATING COSTS (1987 DOLLARS)	UNITS	DAILY UNIT CONSUMPTION	$/UNIT	COST $/DAY	COST $/YR
VARIABLE COSTS					
Electricity	kWh	15,000	0.036	540	197,100
VARIABLE COST SUBTOTAL				540	197,100
FIXED COSTS					
Labor					
Unskilled labor	man-hrs	18	18.67	336	122,662
Supervisory labor	man-hrs	3	24.92	75	27,287
Total Labor Subtotal				411	149,949
Plant Overhead (@ 119% Total Labor)				489	178,440
Maintenance Materials, Labor, Supplies (@ 4% of original CI in 1987 $)				515	188,000
Depreciation (@ 10% of Capital Investment)				103	37,500
Taxes and Insurance (@ 2% of original CI in 1987 $)				258	94,000
FIXED COSTS SUBTOTAL				1775	647,889
TOTAL COSTS				$2,315	$844,989
TOTAL COSTS EXCLUSIVE OF DEPRECIATION, TAXES, & INSURANCE				$1,955	$713,489

Source: Arthur D. Little, Inc.

TABLE 4-3
MICROFILTRATION
(Module 2A)

FEED STREAM:	Poacher Pit Overflow	FEED NC CONCENTRATION:	143 ppm
FEED RATE (3 lines):	5,100,000 gallons per day	FILTRATE NC CONCENTRATION:	0 ppm
CAPITAL INVESTMENT (CI):	$7,790,000	CONCENTRATE NC CONCENTRATION:	100,000 ppm
OPERATIONAL BASIS:	365 days per year		

OPERATING COSTS (1987 DOLLARS)	UNITS	DAILY UNIT CONSUMPTION	$/UNIT	COST $/DAY	COST $/YR
VARIABLE COSTS					
Electricity	kWh	11,235	0.036	404.46	147,628
Membranes	sq ft	37	25.00	925	337,625
Chemicals				164	60,000
VARIABLE COST SUBTOTAL				1,494	545,253
FIXED COSTS					
Labor					
Unskilled labor	man-hrs	9	18.67	168	61,331
Supervisory labor	man-hrs	3	24.92	75	27,287
Total Labor Subtotal				243	88,618
Plant Overhead (@ 119% Total Labor)				289	105,456
Maintenance Materials, Labor, Supplies (@ 4% of Capital Investment)				854	311,600
Depreciation (@ 10% of Capital Investment)				2134	779,000
Taxes and Insurance (@ 2% of Capital Investment)				427	155,800
FIXED COSTS SUBTOTAL				3947	1,440,474
TOTAL COSTS				$5,440	$1,985,727
TOTAL COSTS EXCLUSIVE OF DEPRECIATION, TAXES, & INSURANCE				$2,879	$1,050,927

Source: Arthur D. Little, Inc.

TABLE 4-4
MICROFILTRATION
(Module 2B)

FEED STREAM:	Sliding Bowl Concentrate	FEED NC CONCENTRATION:	650 ppm
FEED RATE (3 lines):	936,000 gallons per day	FILTRATE NC CONCENTRATION:	0 ppm
CAPITAL INVESTMENT (CI):	$1,650,000	CONCENTRATE NC CONCENTRATION:	100,000 ppm
OPERATIONAL BASIS:	365 days per year		

OPERATING COSTS (1987 DOLLARS)	UNITS	DAILY UNIT CONSUMPTION	$/UNIT	COST $/DAY	COST $/YR
VARIABLE COSTS					
Electricity	kWh	2,520	0.036	90.72	33,113
Membranes	sq ft	6.58	30.00	197.4	72,051
Chemicals				123	45,000
VARIABLE COST SUBTOTAL				411	150,164
FIXED COSTS					
Labor					
Unskilled labor	man-hrs	9	18.67	168	61,331
Supervisory labor	man-hrs	3	24.92	75	27,287
Total Labor Subtotal				243	88,618
Plant Overhead (@ 119% Total Labor)				289	105,456
Maintenance Materials, Labor, Supplies (@ 4% of Capital Investment)				181	66,000
Depreciation (@ 10% of Capital Investment)				452	165,000
Taxes and Insurance (@ 2% of Capital Investment)				90	33,000
FIXED COSTS SUBTOTAL				1255	458,074
TOTAL COSTS				$1,666	$608,238
TOTAL COSTS EXCLUSIVE OF DEPRECIATION, TAXES, & INSURANCE				$1,124	$410,238

Source: Arthur D. Little, Inc.

TABLE 4-5
MICROFILTRATION
(Module 3A)

FEED STREAM:	Poacher Pit Overflow	FEED NC CONCENTRATION:	143 ppm
FEED RATE (3 lines):	5,100,000 gallons per day	FILTRATE NC CONCENTRATION:	0 ppm
CAPITAL INVESTMENT (CI):	$7,790,000	CONCENTRATE NC CONCENTRATION:	250,000 ppm
OPERATIONAL BASIS:	365 days per year		

OPERATING COSTS (1987 DOLLARS)	UNITS	DAILY UNIT CONSUMPTION	$/UNIT	COST $/DAY	COST $/YR
VARIABLE COSTS					
Electricity	kWh	11,235	0.036	404.46	147,628
Membranes	sq ft	37	25.00	925	337,625
Chemicals				164	60,000
VARIABLE COST SUBTOTAL				1,494	545,253
FIXED COSTS					
Labor					
Unskilled labor	man-hrs	9	18.67	168	61,331
Supervisory labor	man-hrs	3	24.92	75	27,287
Total Labor Subtotal				243	88,618
Plant Overhead (@ 119% Total Labor)				289	105,456
Maintenance Materials, Labor, Supplies (@ 4% of Capital Investment)				854	311,600
Depreciation (@ 10% of Capital Investment)				2134	779,000
Taxes and Insurance (@ 2% of Capital Investment)				427	155,800
FIXED COSTS SUBTOTAL				3947	1,440,474
TOTAL COSTS				$5,440	$1,985,727
TOTAL COSTS EXCLUSIVE OF DEPRECIATION, TAXES, & INSURANCE				$2,879	$1,050,927

Source: Arthur D. Little, Inc.

TABLE 4-6
MICROFILTRATION
(Module 3B)

FEED STREAM:	Sliding Bowl Concentrate	FEED NC CONCENTRATION:	650 ppm
FEED RATE (3 lines):	936,000 gallons per day	FILTRATE NC CONCENTRATION:	0 ppm
CAPITAL INVESTMENT (CI):	$1,650,000	CONCENTRATE NC CONCENTRATION:	250,000 ppm
OPERATIONAL BASIS:	365 days per year		

OPERATING COSTS (1987 DOLLARS)	UNITS	DAILY UNIT CONSUMPTION	$/UNIT	COST $/DAY	COST $/YR
VARIABLE COSTS					
Electricity	kWh	2,520	0.036	90.72	33,113
Membranes	sq ft	6.58	30.00	197.4	72,051
Chemicals				123	45,000
VARIABLE COST SUBTOTAL				411	150,164
FIXED COSTS					
Labor					
Unskilled labor	man-hrs	9	18.67	168	61,331
Supervisory labor	man-hrs	3	24.92	75	27,287
Total Labor Subtotal				243	88,618
Plant Overhead (@ 119% Total Labor)				289	105,456
Maintenance Materials, Labor, Supplies (@ 4% of Capital Investment)				181	66,000
Depreciation (@ 10% of Capital Investment)				452	165,000
Taxes and Insurance (@ 2% of Capital Investment)				90	33,000
FIXED COSTS SUBTOTAL				1255	458,074
TOTAL COSTS				$1,666	$608,238
TOTAL COSTS EXCLUSIVE OF DEPRECIATION, TAXES, & INSURANCE				$1,124	$410,238

Source: Arthur D. Little, Inc.

TABLE 4-7
SOLID BOWL CENTRIFUGATION
(Module 4)

FEED STREAM:	Bottoms of SB Discharge Pit	FEED NC CONCENTRATION:	6,500 ppm
FEED RATE (3 lines):	93,000 gallons per day	CENTRATE NC CONCENTRATION:	1,000 ppm
CAPITAL INVESTMENT (CI):	$3,130,000	CONCENTRATE NC CONCENTRATION:	260,000 ppm
OPERATIONAL BASIS:	365 days per year	FINES RECOVERY:	85%

OPERATING COSTS (1987 DOLLARS)	UNITS	DAILY UNIT CONSUMPTION	$/UNIT	COST $/DAY	COST $/YR
VARIABLE COSTS					
Electricity	kWh	1,800	0.036	64.8	23,652
VARIABLE COST SUBTOTAL				64.8	23,652
FIXED COSTS					
Labor					
Unskilled labor	man-hrs	6	18.67	112	40,887
Supervisory labor	man-hrs	1	24.92	25	9,096
Total Labor Subtotal				137	49,983
Plant Overhead (@ 119% Total Labor)				163	59,480
Maintenance Materials, Labor, Supplies (@ 4% of Capital Investment)				343	125,200
Depreciation (@ 10% of Capital Investment)				858	313,000
Taxes and Insurance (@ 2% of Capital Investment)				172	62,600
FIXED COSTS SUBTOTAL				1672	610,263
TOTAL COSTS				$1,737	$633,915
TOTAL COSTS EXCLUSIVE OF DEPRECIATION, TAXES, & INSURANCE				$708	$258,315

Source: Arthur D. Little, Inc.

TABLE 4-8
ALKALINE DIGESTION -- 10% SLURRY FEED
(Module 5A)

FEED STREAM: NC Sludge — FEED NC CONCENTRATION: 100,000 ppm

FEED RATE (3 lines): 60,000 lbs per day

CAPITAL INVESTMENT (CI): $1,010,000

OPERATIONAL BASIS: 365 days per year

OPERATING COSTS (1987 DOLLARS)	UNITS	DAILY UNIT CONSUMPTION	$/UNIT	COST $/DAY	COST $/YR
VARIABLE COSTS					
Electricity	kWh	432	0.036	15.552	5,676
Caustic	gal	1.5	200.00	300	109,500
VARIABLE COST SUBTOTAL				316	115,176
FIXED COSTS					
Labor					
Unskilled labor	man-hrs	9	18.67	168	61,331
Supervisory labor	man-hrs	3	24.92	75	27,287
Total Labor Subtotal				243	88,618
Plant Overhead (@ 119% Total Labor)				289	105,456
Maintenance Materials, Labor, Supplies (@ 4% of Capital Investment)				111	40,400
Depreciation (@ 10% of Capital Investment)				277	101,000
Taxes and Insurance (@ 2% of Capital Investment)				55	20,200
FIXED COSTS SUBTOTAL				974	355,674
TOTAL COSTS				$1,290	$470,851
TOTAL COSTS EXCLUSIVE OF DEPRECIATION, TAXES, & INSURANCE				$958	$349,651

Source: Arthur D. Little, Inc.

TABLE 4-9
ALKALINE DIGESTION -- 25% SLURRY FEED
(Module 5B)

FEED STREAM: NC Sludge

FEED NC CONCENTRATION: 250,000 ppm

FEED RATE (3 lines): 24,000 lbs per day

CAPITAL INVESTMENT (CI): $822,000

OPERATIONAL BASIS: 365 days per year

OPERATING COSTS (1987 DOLLARS)	UNITS	DAILY UNIT CONSUMPTION	$/UNIT	COST $/DAY	COST $/YR
VARIABLE COSTS					
Electricity	kWh	432	0.036	15.552	5,676
Caustic	gal	0.6	200.00	120	43,800
VARIABLE COST SUBTOTAL				136	49,476
FIXED COSTS					
Labor					
Unskilled labor	man-hrs	9	18.67	168	61,331
Supervisory labor	man-hrs	3	24.92	75	27,287
Total Labor Subtotal				243	88,618
Plant Overhead (@ 119% Total Labor)				289	105,456
Maintenance Materials, Labor, Supplies (@ 4% of Capital Investment)				90	32,880
Depreciation (@ 10% of Capital Investment)				225	82,200
Taxes and Insurance (@ 2% of Capital Investment)				45	16,440
FIXED COSTS SUBTOTAL				892	325,594
TOTAL COSTS				$1,028	$375,071
TOTAL COSTS EXCLUSIVE OF DEPRECIATION, TAXES, & INSURANCE				[illegible]	$276,431

Source: Arthur D. Little, Inc.

TABLE 4-10
INCINERATION -- 10% SLURRY FEED
(Module 6A)

FEED STREAM: NC Sludge — FEED NC CONCENTRATION: 100,000 ppm

FEED RATE (3 lines): 60,000 lbs per day

CAPITAL INVESTMENT (CI): $6,900,000

OPERATIONAL BASIS: 365 days per year

OPERATING COSTS (1987 DOLLARS)	UNITS	DAILY UNIT CONSUMPTION	$/UNIT	COST $/DAY	COST $/YR
VARIABLE COSTS					
Electricity	kWh	7,000	0.036	252	91,980
Fuel	gal	3312	1.00	3312	1,208,880
Water	1000 gal	82	0.23	19	6,884
VARIABLE COST SUBTOTAL				3,583	1,307,744
FIXED COSTS					
Labor					
Unskilled labor	man-hrs	48	18.67	896	327,098
Supervisory labor	man-hrs	24	24.92	598	218,299
Total Labor Subtotal				1494	545,398
Plant Overhead (@ 119% Total Labor)				1778	649,023
Maintenance Materials, Labor, Supplies (@ 4% of Capital Investment)				756	276,000
Depreciation (@ 10% of Capital Investment)				1890	690,000
Taxes and Insurance (@ 2% of Capital Investment)				378	138,000
FIXED COSTS SUBTOTAL				6297	2,298,421
TOTAL COSTS				$9,880	$3,606,165
TOTAL COSTS EXCLUSIVE OF DEPRECIATION, TAXES, & INSURANCE				$7,611	$2,778,165

Source: Arthur D. Little, Inc.

TABLE 4-11
INCINERATION -- 25% SLURRY FEED
(Module 6B)

FEED STREAM: NC Sludge — FEED NC CONCENTRATION: 250,000 ppm

FEED RATE (3 lines): 24,000 lbs per day

CAPITAL INVESTMENT (CI): $5,700,000

OPERATIONAL BASIS: 365 days per year

OPERATING COSTS (1987 DOLLARS)	UNITS	DAILY UNIT CONSUMPTION	$/UNIT	COST $/DAY	COST $/YR
VARIABLE COSTS					
Electricity	kWh	3,400	0.036	122.4	44,676
Fuel	gal	1728	1.00	1728	630,720
Water	1000 gal	43	0.23	10	3,610
VARIABLE COST SUBTOTAL				1,860	679,006
FIXED COSTS					
Labor					
Unskilled labor	man-hrs	48	18.67	896	327,098
Supervisory labor	man-hrs	24	24.92	598	218,299
Total Labor Subtotal				1494	545,398
Plant Overhead (@ 119% Total Labor)				1778	649,023
Maintenance Materials, Labor, Supplies (@ 4% of Capital Investment)				625	228,000
Depreciation (@ 10% of Capital Investment)				1562	570,000
Taxes and Insurance (@ 2% of Capital Investment)				312	114,000
FIXED COSTS SUBTOTAL				5771	2,106,421
TOTAL COSTS				$7,631	$2,785,427
TOTAL COSTS EXCLUSIVE OF DEPRECIATION, TAXES, & INSURANCE				$5,757	$2,101,427

Source: Arthur D. Little, Inc.

5.0 DISCUSSION AND RECOMMENDATIONS

Table 5-1 summarizes the capital and operating costs for all the NC fines removal/disposal process options.

In addition to the cost associated with each technology, three other factors were assessed and rated. These were:

- The overall recovery of fines;
- The technical risk associated with the process (level of development and additional work required to demonstrate a successful process); and
- The flexibility of the process relative to reliable performance over a range of operating conditions.

Each factor or criteria was rated as to the following scale:

5 Best option to satisfy the criteria
4 Good
3 Average
2 Poor
1 Worst option to satisfy the criteria

The ratings for each option are somewhat subjective, but represent our best judgment after reviewing the available data supporting each technology.

Figure 5-1 summarizes the ratings for each process option. Assuming the criteria are equally weighted, the table also shows the total rating of each option.

The highest rated options were cross-flow microfiltration followed by alkaline digestion followed by biological treatment. They were followed closely by sliding bowl centrifugation to cross-flow microfiltration to alkaline digestion and biological treatment.

The other options with above average scores all involved cross-flow microfiltration as either the sole concentrating step or in tandem with the preconcentrating sliding bowl machines. The poorest rated options incorporated the use of the solid bowl centrifugation.

Though one might argue with the ratings and equal weight of criteria, it appears that a reasonable course of action can be justified after reviewing the results. The following is therefore recommended:

- Since it appears as part of the most attractive options, further more detailed evaluation of the cross-flow microfiltration systems should be undertaken:

TABLE 5-1

SUMMARY OF PROCESS ECONOMICS
(Process Options refer to Table 3-4)

PROCESS OPTION NO.	CAPITAL COST	ANNUAL OPERATING COSTS TOTAL	ANNUAL OPERATING COSTS EXCL. DEPREC TAXES, & INS
I	$4,327,000	$1,853,975	$1,334,735
II	$9,205,000	$4,264,331	$3,159,731
III	$3,035,000	$1,924,078	$1,559,878
IV	$8,925,000	$5,059,392	$3,988,392
V	$2,847,000	$1,828,298	$1,486,658
VI	$7,725,000	$4,238,654	$3,311,654
VII	$8,800,000	$2,456,578	$1,400,578
VIII	$14,690,000	$5,591,892	$3,829,092
IX	$8,612,000	$2,360,798	$1,327,358
X	$13,490,000	$4,771,154	$3,152,354

Source: Arthur D. Little, Inc.

FIGURE 5-1

OVERALL RATING OF PROCESS OPTIONS
FOR REMOVAL/DISPOSAL OF NC FINES

PROCESS OPTION NO.	FINES RECOVERY	TECHNICAL RISK (APPLICATION)	FLEXIBILITY	CAPITAL COST	OPERATING COST	TOTALS
I	1	2	2	4	4	13
II	1	2	1	3	2	9
III	3	3	4	4	3	17
IV	3	3	3	3	2	14
V	3	1	4	5	4	17
VI	3	2	3	3	2	13
VII	5	3	5	3	4	20
VIII	5	4	3	1	2	15
IX	5	1	5	3	4	18
X	5	2	3	2	2	14

KEY

5 BEST
4 GOOD
3 AVERAGE
2 POOR
1 WORST

Source: Arthur D. Little, Inc.

- If it continues to prove feasible, the technical risk will be reduced and options employing the technology will appear even more attractive.

- If it fails to meet expectations, then a reassessment is in order to compare revised performance projections with the less desirable solid bowl centrifuge based options.

- Likewise, since alkaline digestion followed by biological treatment appears to be very flexible and cost effective, a more detailed experimental program should be undertaken to establish the most desirable operating conditions.

  - If this option proves out, it appears to be far more cost effective then incineration.

  - If this option, upon further evaluation, appears impractical, the incineration option is an acceptable alternative.

As a result, it is recommended that small scale on-site pilot testing be carried out using leased equipment for evaluating cross-flow microfiltration. At least one system (vendor) capable of testing various forms of cross-flow filtration (i.e., spiral, hollow tubes, plate and frame) and various membrane types (i.e., loose UF, true microporous, and various materials) should be tried for an extended period (one month of operation). During this test, flux rates, concentration limits, power requirements, cleaning cycles, membrane life, and best overall system configuration should be determined.

It is also recommended that pilot-scale tests on alkaline digestion be undertaken using, if possible, the concentrates produced during the pilot testing of the microfiltration systems. An experimental program to determine optimum digestion temperatures, times and caustic concentration, predigestion requirements, operational configurations and costs should be designed. The effect (both with respect to performance and additional costs) on the existing biotreatment plant should also be assessed during this program. The digests should be evaluated in the existing plant to determine their acceptability as a nitrate replacement and their overall impact on the ability of the plant to accept and treat the additional BOD.

It is also important to note, however, that even though cross-flow microfiltration and alkaline digestion appear to pose no prohibitory safety concerns, a preliminary hazards analysis (PHA) is recommended prior to pilot testing.

6.0 REFERENCES

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(3) Zeigler, E. and R.L. Dickenson, Establishment of Prototype Equipment for the Continuous Separation of Nitrocellulose and Solventless Paste Fines from Plant Effluent. RAD200.10 Final Report to U.S. Army Armaments Command by RAAP, April 1974.

(4) Andren R.K., correspondence to Mr. Donald Maybury regarding results of ultrafiltration tests to remove nitrocellulose fines from poacher pit overflow. Ref. STSNL-YPE, 22 July 1974.

(5) Wendt, T.M. and A.M. Kaplan, A Chemical-Biological Treatment Process for Cellulose Nitrate Disposal, Journal Water Pollution Control Federation, Vol. 48, No. 4, pp.660-668, April 1976.

(6) Economic Evaluation of Incineration of Nitrocellulose (NC) Fines, prepared for USATHAMA by Roy F. Weston, Inc. - W.D. #2281-04-03, June 12, 1987.

(7) R.S. Hall, J. Mattey and K.J. McHaughton, Chemical Engineering, April 5, 1982, pp. 80-116.

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APPENDIX A

ECONOMIC EVALUATION SUMMARY OF
INCINERATION OF NITROCELLULOSE FINES

5.0 SELECTION OF A THERMAL TREATMENT SYSTEM

There are various thermal treatment systems that are suitable for destruction of NC fines. Design and selection is based primarily on the characteristics of the waste stream, cost and efficiency of operation. There are basically two types of thermal treatment systems to evaluate:

1) Direct fired combustion equipment - the flame and/or products of combustion directly contact the waste material (e.g., rotary kiln, multiple hearth furnace, liquid injection incinerator, etc.).

2) Indirect fired combustion equipment - the flame and products of combustion are separated from any contact with the waste material by means of metal/refractory walls (e.g., fluidized bed incinerator, pyrolysis, molten salt reactor, etc.).

The major characteristics of the waste stream to be considered are as follows:

- Thermally sensitive feed stream
- Pumpable liquid slurry, high viscosity
- Minimal ash generation

Since the waste stream is thermally sensitive, indirect fired combustion equipment is preferable. Also, since there are no solids in the feed stream, and little or no ash is expected to be generated, there is no need for equipment that is designed specifically to handle solids (e.g., rotary kiln). With this criteria, it was determined that the optimum selection for thermal destruction of NC fines is a fluidized bed incinerator, which is used most effectively for processing high viscosity sludges.

5.1 Process Description

A process schematic is shown on Figure 2. Detailed information on each component of the system (specific to each concentration scenario) is included on Table 4 in Subsection 6.2.1. A brief discussion is contained herein.

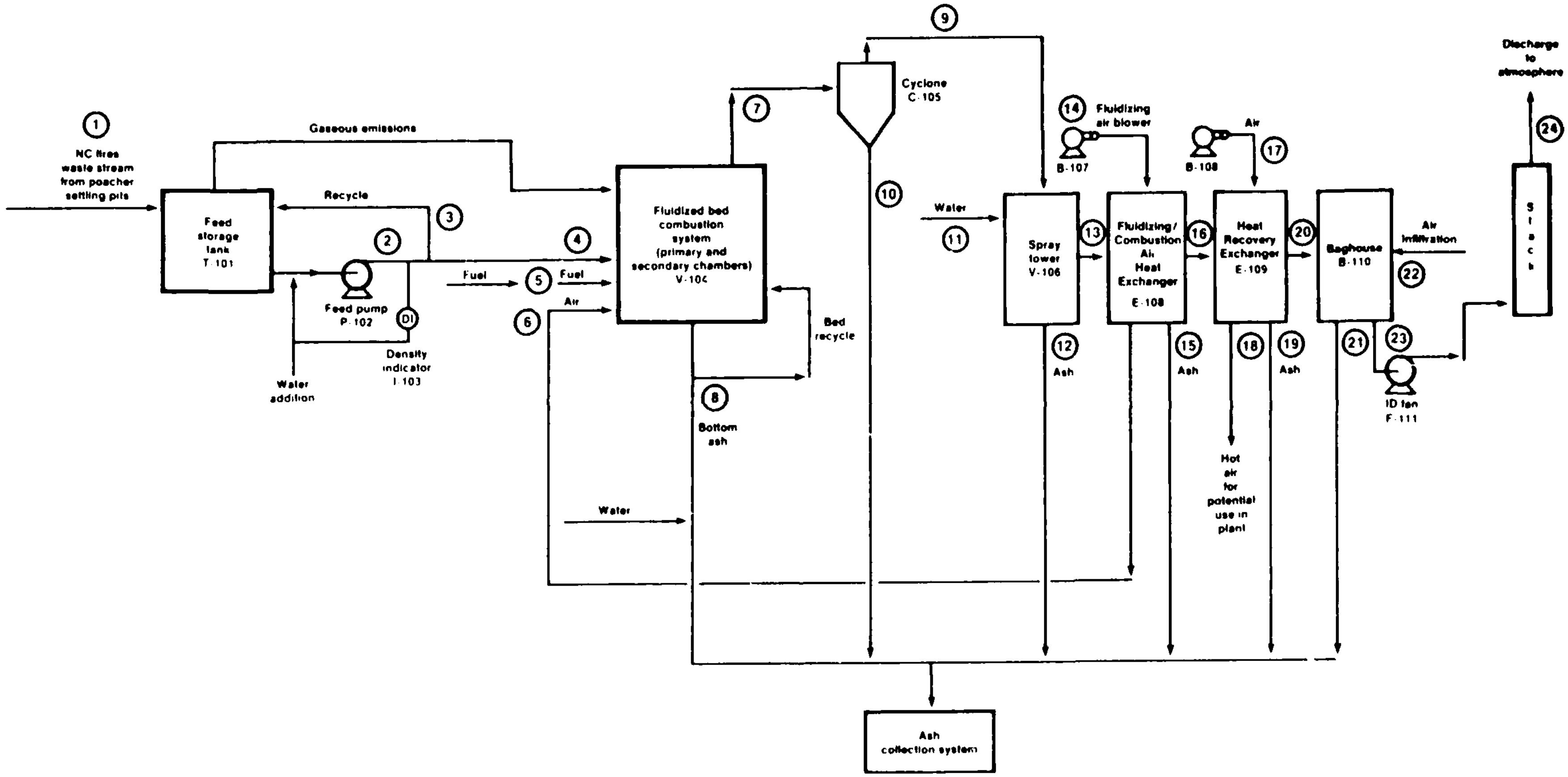


Figure 2 - Process schematic for fluidized bed incineration of NC fires

The NC fines waste stream from the poacher settling pits is collected in the Feed Storage Tank. The tank is designed for one day storage capacity. Feed material is conveyed via a progressing cavity pump to the feed manifold system. A density gauge on the pump discharge line monitors the feed density to determine the percent of NC solids in the waste stream. In the event that NC solids exceed the design level (i.e., 10 percent by weight for Case A), water is added to the storage tank for dilution, thereby reducing the total percent solids. A side stream is recycled from the feed manifold system to the storage tank for mixing purposes and to ensure the NC fines remain in a homogeneous solution. Gaseous emissions from the tank are vented directly into the combustion space in the fluidized bed incinerator.

A series of water-cooled injection nozzles on the feed manifold system utilize high pressure air or steam to propel droplets of the waste stream into the primary chamber combustion space. High pressure air is used to fluidize the bed of magnesium silicate. During operation, the minimum amount of ash that may be generated is removed from the incinerator, cooled with conditioning water sprays to approximately 300°F and collected for disposal.

Off-gases from the primary chamber are directed to an afterburner which is designed to provide a minimum of 2 seconds gas retention time. Flue gases discharge the afterburner at a minimum temperature of 1800°F.

The minimum destruction and removal efficiency (DRE) of the combined primary chamber and afterburner is 99.99 percent. Number 2 fuel oil is used for preheating the bed and auxiliary fuel.

Overhead gases from the afterburner are directed through a spray tower which utilizes water to reduce the temperature of the off-gases to 1000°F. Flue gases are directed through two heat exchangers that operate in series to reduce the temperature to approximately 400°F. The first heat exchanger increases the temperature of the fluidizing/combustion air to approximately 500°F. The second heat exchanger produces air at approximately 500°F that is available for potential reuse in the plant heating system. Particulate fallout is conveyed to the ash collection system.

Exhaust gases enter the fabric filter (baghouse) for particulate removal. The maximum emission level in the baghouse discharge gases is 0.08 grains per dry standard cubic foot (dscf) (corrected to 12 percent carbon dioxide). Particulate is conveyed out of the baghouse hopper and directed to the ash collection system. Baghouse gases are drawn through the induced draft (ID) fan and directed to the stack for atmospheric discharge.

A mass balance for each concentration scenario is provided on Table 5. The weight (pounds per hour (#/hr)) and volumetric flow rate (actual cubic feet per minute (acfm)) for each stream are included. Note that the waste stream composition and flow rates for cases B, C, D and F are very similar; therefore, the same size combustion system can be utilized for these scenarios. In addition, the pressure and temperature of each piece of process equipment is provided on Table 6.

6.0 ECONOMIC EVALUATION

6.1 Economic Assumptions

The following general economic assumptions are applicable to each concentration scenario:

1) The NC fines waste stream is produced on a continuous basis (i.e., 24 hours per day, 365 days per year).

2) All capital costs, as well as operation and maintenance costs, are valued in June 1987 dollars.

3) This economic analysis does not address the estimated costs of environmental permitting.

4) The capital costs presented in this analysis are typical of the costs that would be obtained from a "turnkey" contractor responsible for the design, fabrication, construction, startup, and performance testing of the system.

5) The equipment is designed to provide capacity for maximum production (i.e., three NC production lines in continuous operation). No extra capacity is provided to treat wastes that have accumulated in the recovered water tanks and equalization lagoon.

6) The incineration system will be housed in a building, however, the costs of the building are not included in this evaluation.

7) Cooling water is readily available at no cost and will be supplied at the appropriate pressure by RAAP.

6.2 Capital Costs

The objective of this section is to present the total direct and indirect capital costs for each of the concentration scenarios evaluated. Table 5 provides a summary of the capital costs for each scenario. The format for cost presentation was recommended by A.D.Little.[3]

Table 13

Capital Investment Summary

Installed Cost (1987 Dollars)

Item Number	Description	Case A	Case B	Case C	Case D	Case E	Case F
T-101	Feed Storage Tank	249,600	208,000	155,584	155,584	116,896	155,584
P-102	Feed Pump	84,810	67,650	67,650	57,420	57,420	58,080
I-103	Density Gauge	10,500	10,500	10,500	10,500	10,500	10,500
V-104	Fluidized Bed Combustion System	1,498,000	1,284,000	1,284,000	1,284,000	1,070,000	1,284,000
C-105	Gas/Solid Cyclone	199,680	156,000	156,000	156,000	66,144	156,000
V-106	Spray Tower	832,000	665,600	665,600	665,600	499,200	665,600
B-107	Fluidizing Air Blower	75,616	52,264	52,264	52,264	48,650	52,264
E-108	Fluidizing/ Combustion Air Heat Exchanger	52,080	32,116	32,116	32,116	19,964	32,116
E-109	Heat Recovery Exchanger	41,013	32,116	32,116	32,116	19,964	32,116
B-110	Baghouse	331,200	226,800	226,800	226,800	172,800	226,800
F-111	Induced Draft Fan	50,040	34,750	34,750	34,750	34,750	34,750
C-112	Ash Collection System	232,000	232,000	232,000	232,000	232,000	232,000
C113	Control System	400,000	400,000	400,000	400,000	400,000	400,000
D-114	Ductwork	120,000	90,000	90,000	90,000	60,000	90,000
Installed Equipment		4,176,539	3,491,796	3,439,380	3,429,150	2,808,288	3,429,810
Quality Assurance/ Safety Factor (at 35%)		1,461,789	1,222,129	1,203,783	1,200,203	976,151	1,200,434
TOTAL		5,638,328	4,713,925	4,643,163	4,629,353	3,784,439	4,630,244
Other	Plant Building			*			
	Offices and Laboratories			*			
	Office and Lab Equipment			*			
	Plant Subtotal			*			
	Engineering Fee (3% of Plant Subtotal)			*			
	Contingency (20% of Plant Subtotal)			*			
	Total Capital Investment						

*To Be supplied by A.D. Little

Table 14

Manning Summary for Plant Operation - All Cases

Type	Number	Hours (Man/Year)	Cost ($ Per Hour)	Annual Cost
I. Full Capacity				
Unskilled	8	2184	18.67	326,202
Skilled	-	-	-	-
Supervisory	4	2184	24.92	217,701
Total	12			543,903
II. Two-Thirds Full Capacity				
Unskilled	6	2080	18.67	233,002
Skilled	-	-	-	-
Supervisory	3	2080	24.92	155,501
Total	9			388,503
III. On-Third Full Capacity				
Unskilled	4	2080	18.67	155,334
Skilled	-	-	-	-
Supervisory	2	2080	24.92	103,667
Total	6			259,001

TABLE 15

UTILITIES SUMMARY - CASE A

	Material	Units	Daily Consumption	Cost $ Per Unit	Cost Per day	Cost Per Yr.
I.	Full Capacity					
	Power	Kwh	7,000	0.036	252	91,980
	Fuel	gal	3,312	1.00	3,312	1,208,880
	Water	1000 gal	82	0.23	19	6,935
	TOTAL				3,583	1,307,795
II.	Two-thirds Capacity					
	Power	Kwh	5,133	0.036	185	67,525
	Fuel	gal	2,429	1.00	2,429	886,585
	Water	1000 gal	60	0.23	14	5,110
	TOTAL				2,628	959,220
III.	One-third Capacity					
	Power	Kwh	2,567	0.036	92	33,580
	Fuel	gal	1,214	1.00	1,214	443,110
	Water	1000 gal	30	0.23	7	2,555
	TOTAL				1,313	479,245

TABLE 16

UTILITIES SUMMARY - CASES B, C, D, and F

	Material	Units	Daily Consumption	Cost $ Per Unit	Cost Per day	Cost Per Yr.
I.	Full Capacity					
	Power	Kwh	3,400	0.036	122	44,530
	Fuel	gal	1,728	1.00	1,728	630,720
	Water	1000 gal	43	0.23	10	3,650
	TOTAL				1,860	678,900
II.	Two-thirds Capacity					
	Power	Kwh	2,493	0.036	90	32,850
	Fuel	gal	1,267	1.00	1,267	462,455
	Water	1000 gal	32	0.23	7	2,555
	TOTAL				1,364	497,860
III.	One-third Capacity					
	Power	Kwh	1,247	0.036	45	16,425
	Fuel	gal	634	1.00	634	231,410
	Water	1000 gal	16	0.23	4	1,460
	TOTAL				683	249,295

TABLE 17

UTILITIES SUMMARY - CASES E

	Material	Units	Daily Consumption	Cost $ Per Unit	Cost Per day	Cost Per Yr.
I.	Full Capacity					
	Power	Kwh	2,300	0.036	83	30,295
	Fuel	gal	720	1.00	720	262,800
	Water	1000 gal	22	0.23	5	1,825
	TOTAL				808	294,920
II.	Two-thirds Capacity					
	Power	Kwh	1,687	0.036	61	22,265
	Fuel	gal	528	1.00	528	192,720
	Water	1000 gal	16	0.23	4	1,460
	TOTAL				593	216,445
III.	One-third Capacity					
	Power	Kwh	843	0.036	30	10,950
	Fuel	gal	264	1.00	264	96,360
	Water	1000 gal	8	0.23	2	730
	TOTAL				296	108,040

APPENDIX B

EQUIPMENT LISTS AND COSTS
FOR
THE FOLLOWING MODULES:

- Sliding Bowl centrifugation;
- Cross-flow microfiltration;
- Solid bowl centrifugation; and
- Alkaline digestion.

TABLE B-1
SLIDING BOWL CENTRIFUGATION
(MODULE 1)

EQUIPMENT LIST AND COST
(One NC Manufacturing Line)

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
S-100	Recommision current installation of 8 DeLaval Sliding Bowl Centrifuges Assumes $50,000 labor plus 5% of purchased equipment cost in 1987 $	$125,000	1	$125,000	1.00	$125,000
	PRECONCENTRATION MODULE COST					$125,000

TABLE B-2
MICROFILTRATION/DILUTE FEED
(MODULES 2A and 3A)

EQUIPMENT LIST AND COST
(One NC Manufacturing Line)

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
SP-101	Surge Sump 100,000 Gallon Concrete	$26,000	1	$26,000	1.00	$26,000
P-102	Sump Feed Pump Centrifugal 500 gpm, 30 psi discharge pressure 10 Hp drive	$3,800	3	$11,400	3.38	$38,532
PKG-103	Cross-flow Microfiltration System Prostak unit 13,000 sq ft of membrane (0.2 micron) 316 ss construction on all wetted parts Includes feed pumps, CIP tank and pump system, controls, and explosion-proof motors Vendor: Millipore	$1,950,000	1	$1,950,000	1.05	$2,047,500
	MICROFILTRATION/DILUTE FEED SUBTOTAL			$1,987,400		$2,112,032
	ENGINEERING FEE (3% OF INSTALLED EQUIPMENT)					$63,361
	CONTINGENCY (20% OF INSTALLED EQUIPMENT)					$422,406
	TOTAL CAPITAL INVESTMENT					$2,597,799

TABLE B-3
MICROFILTRATION/PRECONCENTRATED FEED
(MODULES 2B AND 3B)

EQUIPMENT LIST AND COST
(One NC Manufacturing Line)

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
SP-101	Surge Sump 100,000 gallon Concrete	$26,000	1	$26,000	1	$26,000
PKG-102	Cross-flow Microfiltration System Prostak unit 2400 sq ft of membrane 316 ss construction on all wetted parts Includes feed pumps, CIP tank and pump system, controls, and explosion-proof motors Vendor: Millipore	$360,000	1	$360,000	1.1	$396,000
P-103	Sump Feed Pump Centrifugal 500 gpm, 30 psi discharge pressure 10 Hp drive	$3,800	2	$7,600	3.3	$25,080
	MICROFILTRATION/PRECONCENTRATED FEED SUBTOTAL			$393,600		$447,080
	ENGINEERING FEE (3% OF INSTALLED EQUIPMENT)					$13,412
	CONTINGENCY (20% OF INSTALLED EQUIPMENT)					$89,416
	TOTAL CAPITAL INVESTMENT					$549,908

TABLE B-4
SOLID BOWL CENTRIFUGATION*
(MODULE 4)

EQUIPMENT LIST AND COST
(One NC Manufacturing Line)

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
C-101	Centrifuge Solid Bowl, Bird Model L220 (18 x 28)	$175,000	2	$350,000	2.37	$829,500
P-102	Feed Pump 25 gpm, 50 psi discharge pressure 316 ss	$2,500	1	$2,500	3.38	$8,450
P-103	Sludge Pump 316 ss	$2,900	1	$2,900	3.38	$9,802
	SOLID BOWL CENTRIFUGATION SUBTOTAL			$355,400		$847,752
	ENGINEERING FEE (3% OF INSTALLED EQUIPMENT)					$25,433
	CONTINGENCY (20% OF INSTALLED EQUIPMENT)					$169,550
	TOTAL CAPITAL INVESTMENT					$1,042,735

*Assumes no special clairification/concentration device is required to concentrate the sliding bowl centrifuges' concentrate to 6,500 ppm solids as feed to the solid bowl centrifuge

TABLE B-5
ALKALINE DIGESTION
(10% FEED - MODULE 5A)

EQUIPMENT LIST
(One NC Manufacturing Line)

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
T-101	Feed Storage Tank Glass-lined carbon steel Vertical cylindrical Sized to hold one days production; 2,500 gallons	$24,000	1	$24,000	2.55	$61,200
P-102	NC Slurry Feed Pump Model No. 1L3 CDQ Progressing cavity pump 316 ss steel internals and castings 316 ss/chrome plated rotor BUNA N STATOR Variable speed drive 20 psig discharge pressure 1 HP explosion proof motor	$2,900	1	$2,900	3.38	$9,802
T-103	Caustic Storage Tank Low alloy carbon steel Sized for 2 weeks supply of 40% caustic; 5,000 gallons diked enclosure	$13,500	1	$13,500	2.55	$34,425
P-104	Caustic Metering Pump 316 ss 5 gph	$600	1	$600	3.38	$2,028
T-105	Predigestion Reactor Nauta Mixter Model FA-ID Conical, externally supported, 316 ss steam jacketed tank with 3 HP rotating screw mixer, dished head with glass viewport and dual charging ports 77 gallon capacity with 8" dia. slide gate discharge Vendor: Day Mixing Co.	$43,500	1	$43,500	2.90	$126,150
P-106	Digest Slurry Pump Model No. 1L3 CDQ Progressing cavity pump BUNA N STATOR Variable speed drive 50 psig discharge pressure 2 HP explosion proof motor	$2,900	1	$2,900	3.38	$9,802
X-107	Hydroheater Steam injection cooker 316 ss construction per vendor design specifications Vendor: Hydrothermal	$2,300	1	$2,300	3.00	$6,900
R-108	Reactor Serpentine tubular reactor 10x10 ft 8" dia. sections Low alloy carbon steel	$2,500	1	$2,500	4.00	$10,000
T-109	Receiving Tank Low alloy carbon steel Vertical cylindrical Sized to hold 2 hours of capacity; 200 gallons with side mounted 3/4 Hp agitator	$3,000	1	$3,000	2.55	$7,650

TABLE B-5
ALKALINE DIGESTION
(10% FEED - MODULE 5A)

EQUIPMENT LIST
(One NC Manufacturing Line)

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
P110	Transfer Pump Centrifugal Low alloy carbon steel 10 gpm, 30 psig discharge pressure	$1,400	1	$1,400	3.38	$4,732
	ALKALINE DIGESTION - 10% FEED SUBTOTAL			$96,600		$272,689
	ENGINEERING FEE (3% OF INSTALLED EQUIPMENT)					$8,181
	CONTINGENCY (20% OF INSTALLED EQUIPMENT)					$54,538
	TOTAL CAPITAL INVESTMENT					$335,407

TABLE B-6
ALKALINE DIGESTION
(25% FEED - MODULE 5B)

EQUIPMENT LIST
(One NC Manufacturing Line)

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
T-101	Feed Storage Tank Glass-lined carbon steel Vertical cylindircal Sized to hold one days production; 1,000 gallon capacity	$15,000	1	$15,000	2.55	$38,250
P-102	NC Slurry Feed Pump Model No. 1L3 SSQ Progressing cavity pump 316 ss internals and castings 316 ss/chrome plated rotor BUNA N STATOR Variable speed drive 20 psig discharge pressure 1 HP explosion proof motor	$2,900	1	$2,900	3.38	$9,802
T-103	Caustic Storage Tank Low alloy carbon steel Sized for 2 weeks supply of 40% caustic; 2,000 gallons diked enclosure	$8,500	1	$8,500	2.55	$21,675
P-104	Caustic Metering Pump 316 ss 5 gph	$600	1	$600	3.38	$2,028
T-105	Predigestion Reactor Nauta Mixer Model FA-7 Conical, externally supported, 316 ss steam jacketed tank with 3 HP rotating screw mixer, dished head with glass view port and dual charging portse 52 gallon capacity with 8" dia. slide gate discharge Vendor : Day Mixing Co.	$41,500	1	$41,500	2.90	$120,350
P-106	Digest Slurry Pump Model No. 1L3 SSQ Progressing cavity pump BUNA N STATOR Variable speed drive 50 psig discharge pressure 2 HP explosion proof motor	$2,900	1	$2,900	3.38	$9,802
X-107	Hydroheater Steam injection cooker 316 ss construction per vendor design specifications Vendor: Hydrothermal	$2,300	1	$2,300	3.00	$6,900
R-108	Reactor Serpentine tubular reactor 4x10 ft 8" dia sections Low alloy carbon steel	$1,000	1	$1,000	4.00	$4,000
T-109	Receiving Tank Low alloy carbon steel Vertical cylindrical Sized to hold 2 hours of capacity; 80 gallons with side mounted 1/2 Hp agitator	$2,100	1	$2,100	2.55	$5,355

TABLE B-6
ALKALINE DIGESTION
(25% FEED - MODULE 5B)

EQUIPMENT LIST
(One NC Manufacturing Line)

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
P-110	Transfer Pump Centrifugal Low alloy carbon steel 10 gpm,30 psi discharge pressure	$1,400	1	$1,400	3.38	$4,732
	ALKALINE DIGESTION -- 25% FEED SUBTOTAL			$78,200		$222,894
	ENGINEERING FEE (3% OF INSTALLED EQUIPMENT)					$6,687
	CONTINGENCY (20% OF INSTALLED EQUIPMENT)					$44,579
	TOTAL CAPITAL INVESTMENT					$274,160

APPENDIX C

VENDORS' REPORTS ON MICROFILTRATION STUDIES

- Millipore
- Koch/ABCOR

July 10, 1987

Mr. John Nystrom
A. D. Little, Inc.
25 Acorn Park
Cambridge, MA 02140

Dear John:

Attached you will find a brief report describing the results of the nitrocellulose waste stream.

As I stated within the report, I was unable to evaluate other membrane types due to lack of fluid volume. Other membrane types may show enhanced performance. This aspect can be investigated in the early stages of a pilot evaluation.

Feel free to call if you have any questions concerning the data, future pilot work, or ultimate system design. Mark Greene, our area sales engineer, can assist you with system pricing and rental costs. He can be reached at (315)451-7581.

I also have samples of the final concentrate and composite permeate, if you need them. I look forward to working with you soon.

Sincerely

MILLIPORE CORPORATION

Marty Siwak
Process Engineer
Systems Division

/bh

Enclosure

CLARIFICATION OF A WASTE STREAM
FROM NITROCELLULOSE MANUFACTURING

JULY 1987

INTRODUCTION

Millipore has been contacted by A. D. Little, Inc. to evaluate the feasibility of clarifying a nitrocellulose waste stream by tangential flow filtration.

The waste stream is derived from nitrocellulose manufacturing at the Radford Army Ammunition Plant in Radford, Virginia. The stream is composed of 150-250 ppm of nitrocellulose fines and 150-250 ppm of dissolved solids. The objective is to clarify the stream of the suspended solids for acceptable discharge, and to concentrate the nitrocellulose to greater than 10% solids, preferably to 25% solids.

METHODS

Approximately, 13 gallons of feed material were received from John Nystrom of A.D.L. The sample appeared as a milky-white suspension. The sample was well mixed prior to testing.

Module	PROSTAK^{tm}, 2.0ft^2
Membrane	0.65u DVPP microporous
Pump	Rotary lobe, 0-20 gpm
Temperature	30-35^{o}C

Prior to concentration, the material was run in total recycle to evaluate flux decay as a factor of time. The material was then concentrated at 50-55 psi, at 2.5 gpm/channel. Flux was monitored as a function of volumetric reduction. Concentration was limited to 32 fold volumetric reduction within the PROSTAK system due to holdup volume. The concentrate was then transferred to a lab scale Minitan filtration device where the material was concentrated to 550 fold using 0.65u membrane.

The PROSTAK module was cleaned with a 0.5% Tergazyme solution.

RESULTS

Figure 1 depicts the flux decay data at both 10 and 20 psi. Flux is shown as a function of time in units of liters/meter^2/hr (lmh) and gallons/ft^2/day (gfd). Initial flux was approximately 200 gpd, which drops rapidly to a stable 25 gfd at 10 psi after 30 minutes. When the pressure is increased to 20 psi flux rises to 160 gfd, which falls to approximately 115 gfd after 20 minutes. This behavior is typical of cake foaming suspensions.

Figure 2 depicts flux versus volumetric concentration factor where concentration factor is defined as the initial volume divided by the concentrated volume. These fluxes are normalized to 25°C operating temperature. Flux rates are initially 300 gfd at 50 psi, which dropped to 125 gpd at 10 fold volumetric reduction. The decline in flux is more likely to be a function of time rather than the concentration factor, since the initial suspended solids content is very low at approximately 200 ppm.

Flux remained stable at 125 gfd from 10 fold through approximately 100 fold; flux declined to approximately 80 gfd at 550 fold. The data at 100 fold and 550 fold were generated on the Minitan device at conditions that would closely reproduce that of the PROSTAK. It is estimated that the final suspended solids content was approximately 8.5 to 13.7% based on initial solids content.

The data shown in Figure 2 indicates that concentration to greater than 20% suspended solids is possible.

The PROSTAK module was cleaned with a solution of 0.5% Tergazyme, a surfactant-based cleaner. Implementation of back flushing techniques in combination with Tergazyme recovered 100% of the initial water flux.

Due to the low volume of feed material, alternative membrane types and filtration devices were not evaluated. Likewise, the investigation of a full range of pressure and cross flow conditions were not within the scope of this feasibility test. The potential for improved flux may exist if these variables are examined.

CONCLUSIONS

- The nitrocellulose fines waste stream, as received here, can be successfully concentrated and clarified by using Millipore PROSTAK modules.
- Concentration to greater than 20% suspended solids can be expected.
- The membrane was easily cleaned using a surfactant-based cleaning agent coupled with back flushing techniques.
- Average fluxes in the range of 120-150 gfd can be expected at 25°C and 50 psi.
- Further evaluations are recommended, initially on a small scale to select the most appropriate membrane type, followed by long-term piloting to develop scale-up data.

/bh

FIG 1

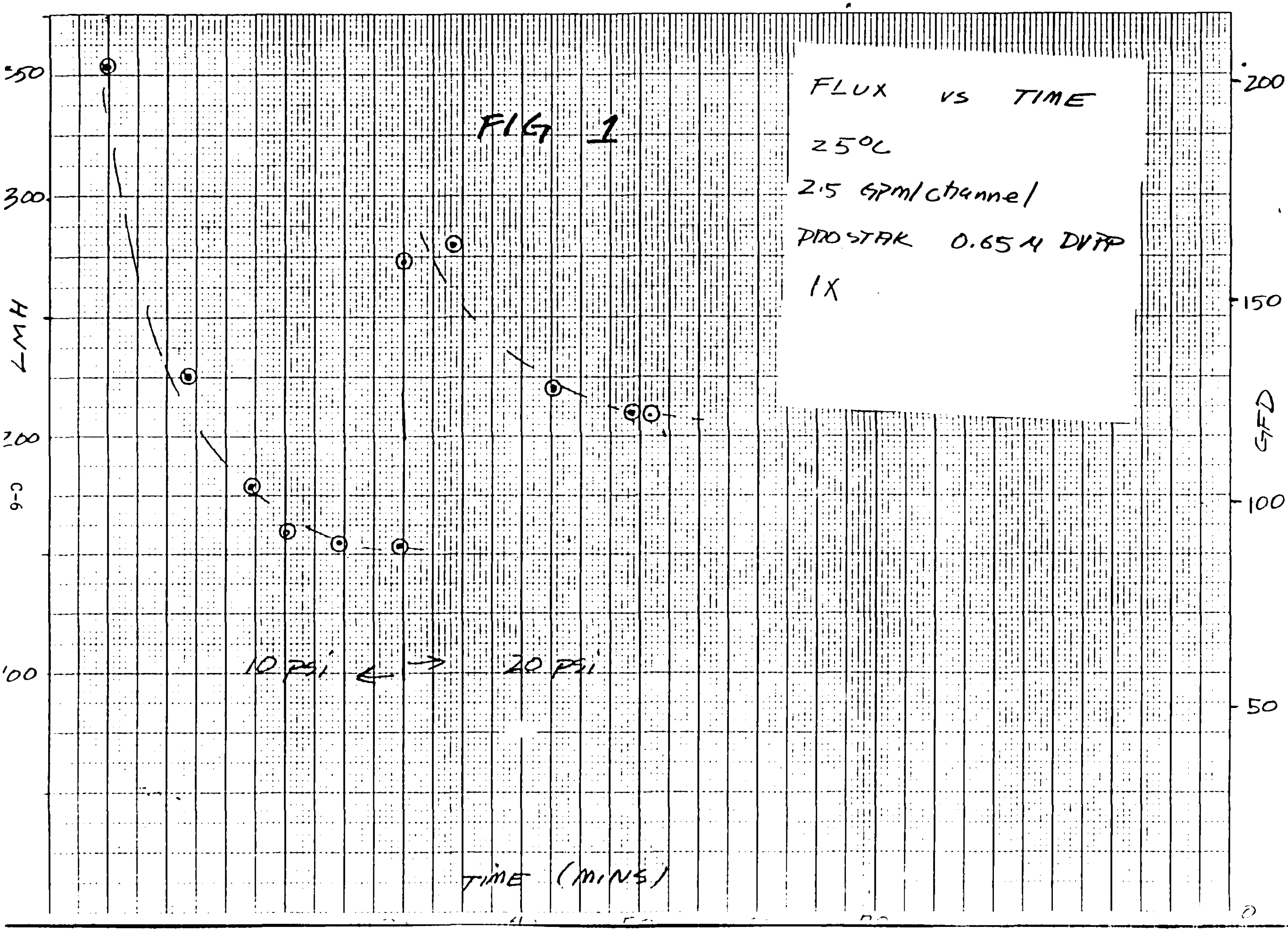
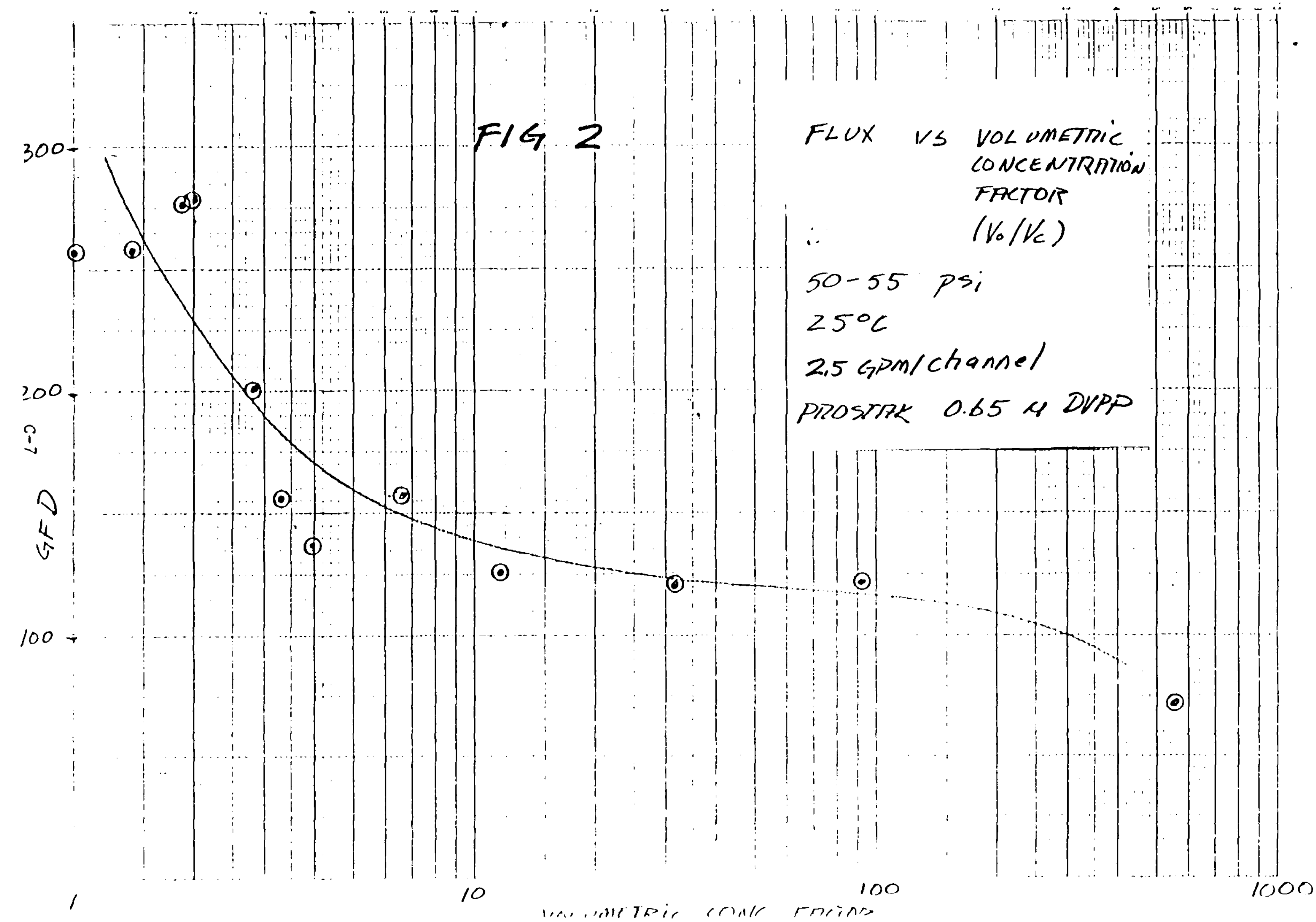

FLUX vs TIME
25°C
2.5 GPM/channel
PROSTAK 0.65 μ DVPP
1X
LMH
350
300
200
100
GFD
200
150
100
50
0
10 PSI ← → 20 PSI
TIME (MINS)

FIG 2



FLUX VS VOLUMETRIC CONCENTRATION FACTOR (V_o/V_c)
50-55 psi
25°C
2.5 GPM/channel
PROSTAK 0.65 μ DVPP
300
200
100
GFD
1
10
100
1000

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